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14. ABSTRACT  This final report covers the activities conducted by Dr. Timothy Broderick during his participation in planning and execution of the NASA Extreme Environment Mission Operation (NEEMO) 9 mission. The mission, held in collaboration with NASA, was conducted from April 3 – 20, 2006. Dr. Broderick served as an aquanaut aboard the Aquarius habitat, which is submerged off the coast of Key Largo, FL. During this mission, Dr. Broderick participated in research led Dr. Mehran Anvari and McMaster University as well as NASA activities. The principal focus of the McMaster University research was telemedicine and telesurgery.					
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## INTRODUCTION

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The ability to conduct research in analog environments is of tremendous value to NASA and the U.S. military. Each of these government entities place men and women in extreme environments. The technology developed, adapted, and integrated in these analog environments can improve healthcare delivery in an extreme environment.

The National Oceanographic and Atmospheric Administration (NOAA) / National Undersea Research Center (NURC) Aquarius habitat, located off the coast of Key Largo, FL, and submerged to a depth of approximately 13 fathoms (75 feet), serves as a research facility for a variety of organizations. One program that utilizes this extreme environment is known as National Aeronautics and Space Administration (NASA) Extreme Environment Mission Operations (NEEMO). The successful conduct of eight prior NEEMO missions led to NEEMO 9.

NEEMO 9 was a collaborative research and training mission involving the following organizations: Telemedicine and Advanced Technology Research Center (TATRC), NASA, National Space Biomedical Research Institute (NSBRI), Canadian Space Agency (CSA), NOAA, U.S. Navy, SRI, Centre for Minimal Access Surgery (CMAS) at McMaster University, and the Center for Surgical Innovation (CSI) at the University of Cincinnati (UC). The overall science effort was coordinated by Dr. Mehran Anvari at CMAS.

UC's Dr. Timothy Broderick served as an aquanaut, living underwater for 18 days with three NASA astronauts (Dave Williams, MD, Nicole Stott, and Ronald Garan). This effort was of direct benefit to TATRC research programs, facilitated further development of TATRC relationships with other mission partners, and thereby, will translate into improved medical research and care of the warfighter.

The overall objective was to explore the use of simulation, telementoring, and telerobotic surgery to enable a non-physician astronaut to perform emergency diagnostic and surgical procedures in an extreme environment. This mission was to explore new techniques and develop new technologies necessary to make telesurgery and telerobotic manipulation more "effective" and relevant in everyday surgical practice as well as in provision of life and limb saving emergency surgery to an injured soldier in the battlefield. This program also sought to answer a fundamental question related to the human brain's ability to adapt to latency produced by distances for signals to travel during a telerobotic operation. This research had significance not only for telerobotic surgery but for all other instances where robotic manipulators, vehicles, or equipment will be operated from a distance.



## **BODY**

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### **RESEARCH PLAN**

The research planned and conducted aboard the NEEMO 9 mission was developed and coordinated by several organizations, including CMAS, NASA, and NSBRI. The Institutional Review Boards (IRB) at CMAS, NASA, UC, and TATRC all reviewed and approved the research. Dr. Timothy Broderick served on the mission management team and as an aquanaut. He developed and participated in all of the science activities.

### **Methods**

A crew of 4 individuals consisting of non-physician astronauts, physician astronauts, and a TATRC surgeon aquanaut performed research within the Aquarius habitat. During this 18-day mission, the crew evaluated adaptation of the human brain to increasing latency experienced during performance of virtual telerobotic tasks. In addition, the crew would also evaluate the ability of inexperienced care providers using simulation and telementoring to perform emergency surgical tasks in an extreme environment. Multiple TATRC medical technologies were also scheduled to be evaluated in an extreme environment.

The NEEMO 9 research plan included:

1. Establishment a high quality two-way video and audio connectivity between crew in Aquarius and physicians and surgeons in CMAS using microwave, wireless Internet Protocol (IP), Internet and satellite capabilities;
2. Establishment of wireless IP telecommunication link up between land base (Key Largo) and Aquarius for performing a variety of telerobotic tasks;
3. Evaluation of the ability of a surgeon and a non-surgeon astronaut/soldier to perform a variety of complex tasks in an extreme environment under increasing time delays and under different stressors;
4. Mapping of the region of brain involved in adaptation to latency increases and different environmental stressors;
5. Evaluation of a number of human performance questions about physicians and non-physicians operating under stress in extreme environments;
6. Evaluation of the ability of a non-physician or non-surgeon to deliver emergency diagnostic, and surgical care including fracture management and anesthesia; and
7. Testing a number of new telerobotic, diagnostic and surgical tools developed by TATRC.

Dr. Broderick role in this research effort was to:

- Participate in planning meetings conducted either in person or through a telecommunications link;
- Participate in training in support of diving and research;
- Dive on the 18 day mission as one of the aquanauts;



- Help design and perform research during the 18 day mission;
- Participate in a variety of educational outreach and media events;
- Participate in preparation of reports, data analysis and manuscripts;
- Cultivate relationship between TATRC and partnering organizations;
- Insure success of TATRC funded project through internal facilitation; and
- Present project and experimental data at appropriate TATRC-related meetings.

## Research Goals and Objectives

The research goals and objective of the research included:

*The primary goal of this project was to test the effectiveness of telehealth (telementoring and telerobotic surgery) in an extreme environment to offer emergency diagnostic and life or limb saving surgery in the absence of a physician.*

The secondary goals were:

- (1) to train three astronauts with the use of robotic surgical technology;*
- (2) to test the use of small portable robotic technology;*
- (3) to evaluate the minimum telecommunication parameters necessary for safe and effective delivery of above services; and*
- (4) to evaluate U.S. military and NASA advanced technologies*

## Project Timeline

Preparation for the mission occurred in the months prior to splash down. Splash down (the actual diving to the habitat) took place on April 3, 2006. This mission lasted until April 20, 2006, when the crew splashed up (surfaced).

## MILITARY RELEVANCE

Provision of emergency diagnostic and medical care in an extreme environment is of significant interest to the U.S. Army. Telesurgery has been identified by TATRC as a prime area of medical research for the next decade. Robotic telesurgery is also of interest to DARPA as evidenced by the Trauma Pod Program. Of note, this research was designed in consultation with Dr. Broderick of TATRC and Dr. Richard Satava of DARPA. This program utilized and evaluated the SRI M-7, telesurgical robotic platform developed by SRI for the U.S. military. This project helped TATRC and DARPA further develop telesurgery and focus future research investment.

## BUDGET

The value of this award was \$49,361. These funds were allocated to the University of Cincinnati. The funds were used to support salary, fringe, travel and equipment.



The personnel costs were solely for the PI, Dr. Timothy Broderick. Travel costs, budgeted for \$12,500 total, were utilized to support domestic and international travel associated with this project.

There were no indirect costs associated with this project

## **KEY RESEARCH ACCOMPLISHMENTS**

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The following summarizes the activities that Dr. Broderick participated in during the NEEMO 9 mission. In addition, the entire crew report from NEEMO 9 is included in Appendix 3.

### **1) Aquarius as a Space Telemedicine analog**

#### **Center for Minimal Access Surgery (CMAS) at McMaster University**

### **1) CMAS 1 – Impact of Latency on Brain Activity and Task Performance.**

In this experiment, NASA crew members performed 3 virtual reality (VR) tasks while having their brain activity recorded by dense array electroencephalogram (EEG). The VR tasks included ball catch, box draw and arc draw under conditions of latency that ranged from 0 – 750 msec. Variable auditory stress was also imposed during task performance that included white noise and simulated helicopter in flight.

A significant amount of the mission timeline was dedicated to this experiment. Concerns regarding electromagnetic interference (EMI) limiting quality of EEG data gathered in the habitat appear unfounded. The crew successfully placed EEG nets on each other and set up a fairly complex EEG monitoring system in part secondary to excellent training, procedures and in-mission support. Despite the technical challenges that resulted from laptop and amplifier failure, significant data was collected and the experiment was successful.

Preliminary data analysis suggests dense array EEG monitoring is possible in Aquarius. This represents the first time dense array EEG data were collected during undersea saturation and under various latency conditions. The crew subjectively noted adaptation to latency.

### **2) CMAS 2 – Acquisition and Interpretation of Digital Radiographs in an Extreme Environment.**

In this experiment, non-medical NASA crew (RG and NS) explored the ability of a non-medical Crew Medical Officer (CMO) to obtain and interpret digital radiographs in an extreme environment. There was significant overhead in modifying (removing x-ray tube) and potting the relatively large and heavy digital x-ray machine down to the habitat. The crew successfully used this equipment and the CMAS Extreme Radiology Manual to simulate acquisition of AP and lateral wrist and ankle images. Digital radiographs that had been previously taken at CMAS were



successfully transferred to CMAS and then interpreted by crew. The CMAS Extreme Radiology Manual was excellent.

The experiments confirmed that non-medical CMO could obtain digital radiographs quickly and efficiently when supported by an appropriate manual. Non-medical crew successfully recognized abnormal radiologic findings such as small fractures when radiographs were compared with radiographs of the contralateral normal limb. These experiments suggest that an appropriately supported CMO can acquire and interpret digital radiographs as necessary during future space exploration.

3) CMAS 3 - Telementored External Fixation of a Tibial Fracture.

In these experiments, NASA crew members simulated telementored external fixation of a tibial fracture. A medical and non-medical crew member performed the external fixation with telementoring under real time latency (@ 200 msec). The other medical and non-medical crew members performed the fixation with telementoring under lunar latency (2 sec). The simulated tibia and fibula were adequate despite the lack of overlying soft tissue. The crew was concisely trained prior to the mission in use of the external fixation equipment and appropriate anatomy. The telementoring of Dr. Tony Adile from CMAS was excellent.

Data analysis is underway. Expert telementor and telementee overcame lunar latency to permit successful, efficient fixation of a tibial fracture. Fixator constructs were solid and suggested possible benefit in treatment of open fractures during future space exploration. Additional research clarifying the role of external fixation is necessary. Telementoring could augment medical care provided during future lunar exploration.

4) CMAS 4 – Telementored Knee Ultrasonography and Simulated Arthroscopy.

In these experiments, medical and non-medical crew members imaged the knee of a crew member using ultrasound (US). They then used standard arthroscopic equipment and an inanimate simulator to perform knee arthroscopy. Two crew members were more extensively trained prior the mission in knee US. These crew members used an excellent knee US manual and also were expertly telementoring by Dr. Julian Dobranowski under real time latency (@ 200 msec). The other medical and non-medical crew members performed similar tasks with minimal pre-mission training and telementoring under lunar latency (2 sec). All crew members performed knee arthroscopy after basic arthroscopic pre-mission training using an excellent knee arthroscopy manual. Expert telementoring was provided at the previously mentioned latencies. Pre-mission training was appropriate for both groups. Telementoring of Drs. Dobranowski and Adile from CMAS was excellent.

Data analysis is underway. Expert telementor and telementee overcame lunar latency to permit successful, efficient imaging of the knee via US. Simulated telementored arthroscopic diagnosis and treatment of knee pathology was also





successful. US and MIS surgery could be of benefit in the diagnosis and treatment of musculoskeletal injuries during future space exploration. Addition research clarifying the role of musculoskeletal US and MIS surgery is necessary. Telementoring could augment medical care provided during future lunar exploration.

5) CMAS 5 – Telepresence Surgery Using a Portable Robotic System.

These experiments were a scientific high point of the mission. With successful pre-mission training, the crew successfully assembled and facilitated remote use of the SRI International M7 Telepresence Surgical System. This represents the first time that such a system has been successfully deployed and used in an extreme environment. In addition, this was the first time that a surgeon (Dr Anvari in Hamilton, Ontario) was able to overcome induced latency of over 2 seconds.

During the first day of experiments, significant weather and wave action impaired microwave communication from the LSB to the NURC base. The network provided connectivity that initially permitted limited telesurgical manipulation. The bandwidth of the microwave connection was estimated at 10 Mbps maximum during these initial experiments. However, usable bandwidth was significantly decreased by concurrent mission activities such as PAO videoteleconferences. Latency was at times as high as 4 sec and jitter was up to 1 sec. The bandwidth, latency and jitter forced us to limit concomitant network traffic and decrease robot cycle rate (to limit bandwidth use).

Multiple re-initializations during the rectification of network issues result in a mechanical failure of one of the robotic arms. The failure posed no safety risk but did preclude grasping with the instrument. Crew recognized failure and using the VBrick Internet video image proposed repair to the topside SRI engineer. The crew subsequently fixed the system via reapproximation/cementing of the stripped rod at the point of the robotic arm/end effector interface.

Software and hardware failure in CMAS 1 allowed addition of a second day of CMAS 5 experimentation. Successful suturing and lunar sample analysis occurred on the second day. With the network and mechanical issues resolved, Dr. Anvari was able to successfully suture a simulated laceration at lunar latency. He also used the telerobotic system to manipulate simulated lunar rock samples under the direction of JSC lunar geologists.

Successful telesurgery in an extreme environment at lunar latency was very well received by our academic, industrial and military collaborators. The print and broadcast media provided very positive coverage of these telesurgery experiments.

Further evaluation of the role of medical and non-medical telerobotics in space exploration is warranted.



6) CMAS 6 – Haptic Telementoring.

In these experiments, the crew successfully used a haptic telementoring system provided by Handshake VR. Their device uses proprietary hardware and software to ameliorate latency and thereby improve the stability of a distributed haptics system. Using this system, the crew members were able to “feel” simulated virtual tissue as well as the remote guidance of Dr. Anvari. These limited experiments suggest that latency can be ameliorated to support haptic telementoring at latencies up to approximately 500 msec. Future telehaptics research is required to further mitigate the effect of latency and discern appropriate medical applications.

**University of Nebraska In Vivo Robots.**

In these experiments, the crew evaluated use of prototype small intracavitary surgical robots. The crew compared surgical procedure performance in an inanimate simulator using roboscopic and standard laparoscopic imaging systems. The tasks performed included: rope run, grasp/cut, and appendectomy. The robots performed well. Their mobility subjectively improved the view by allowing the operators to see around objects that limited the view provided by the standard laparoscope. Data analysis is underway. Limited analysis suggests that mobile intracavitary robots could provide better viewing angles that could translate into improved surgical performance. Furthermore, small deployable robots could permit minimally invasive diagnostic and limited therapeutic capabilities in extreme environments. Further research and development of these systems is underway. This research was well covered by print and broadcast media.

**NSBRI SCIENCE**

Five experiments from the NSBRI evaluated individual and group performance on the longest NEEMO and Aquarius mission to date. Baseline data collection occurred pre-mission and data was collected both during and after the mission. Pre-mission experiment hardware training was given at Johnson Space Center. The following is a brief description of the experiments and crew comments where applicable.

1) NSBRI 1 – Linguistic, Physical, and Cognitive Indices of Group Process and Interpersonal Communication in Remote, Isolated Environments.

Long duration space flight can lead to problems associated with group dynamics. It will be critically important for crews to continue to work together effectively while being confined to small spaces far from Earth for long periods of time. Group dynamics (language, physical cues, and implicit cognitions) could have an impact on constructs such as leadership, information-sharing, dominance, or situational awareness. Group dynamics factors could be useful in predicting team breakdown or task failure.



The majority of the data analysis occurred post-mission using video and voice recordings of team task work (e.g., telemedicine tasks, EVAs, and others if scheduled). Crew time requirements for data collection were minimal. Crew members completed a brief (approximately five-minute) cognitive reaction time task via computer after the four telemedicine tasks.

2) NSBRI 2 – The Effectiveness of Embedded Cognitive Performance Readiness Measures in a Telemedicine / Telesurgery Spaceflight Analog Environment.

In spaceflight, astronauts will be required to do many different critical tasks, potentially with associated stress. The development of embedded performance tests that can be successfully related to performance readiness metrics could give the astronaut and mission control information on the best time to perform critical events as well as an assessment of the need for countermeasures.

The two cognitive measures used were the MiniCog/Rapid Assessment Battery (MRAB) and the Perceptual Vigilance Test (PVT). Both tests contain tasks that allow investigators to distinguish between the effects of stress and fatigue on performance. The two measures of stress will be cortisol level and computerized optical recognition metrics based on habitat surveillance video.

There were no issues with either the MRAB or PVT hardware and the amount of time allocated in the timeline for each portion of the experiment was appropriate.

3) NSBRI 3 – Team Cohesion and Productivity, Stress Indicators, Readiness to Perform.

Long duration space flight can lead to problems associated with group dynamics. It will be critically important for crews to continue to work together effectively despite being confined to small spaces far from Earth for long periods of time. This study was designed to assess individual astronaut and crew performance readiness, stress levels, and effectiveness as a team. The data collected will help researchers learn how to improve and refine tools for real time monitoring and develop predictive models that can be tested in other analog studies. The eventual goal is to develop a suite of tools that astronauts can use in spaceflight.

Data collection began with mission training and included a session of pre-mission interviews. Follow-up interviews were conducted following the mission.

4) NSBRI 4 – Sleep/Wake Actigraphy and Light Exposure Measures in an Extreme Environment.

The success and effectiveness of human space flight depends on the ability of crewmembers to maintain a high level of cognitive performance and vigilance while operating and monitoring sophisticated instrumentation. However, astronauts commonly experience sleep disruption and may experience circadian phase misalignment during space flight. Relatively little is known of the prevalence or cause



of space flight-induced insomnia in short duration missions, and less is known about the effect of long-duration space flight on sleep and circadian rhythm organization.

Crewmembers used an Actiwatch to monitor sleep-wake activity patterns and light exposure. The Actiwatch was removed prior to diving and put on after returning to the habitat. A brief written evaluation of sleep quality and daytime alertness was recorded daily.

There were no hardware or timeline issues associated with this experiment.

#### 5) NSBRI 5 - Psychophysiological Measures During Confinement in an Underwater Habitat

Certain phases of long duration space flight may require monitoring psychophysiological measures on individual crewmembers. The means to measure this data cannot interfere with the crew's ability to function effectively. This study obtained human physiological data of crewmembers during normal working hours while wearing an ambulatory monitoring system (AMS). The signal quality, ease of operation, and crew comfort of the AMS was assessed. Two crewmembers (DW and RG) wore the AMS during the day on 3 days during the mission.

Overall, the AMS was not unobtrusive. The garment kept the subjects warm in the cool environment of the habitat but this would be a problem if the subjects had to exercise while wearing the garment. It could also be an issue if the temperature of the habitat were higher. Use of a garment to hold the sensors and wires creates the need to either be able to wash the garment or have multiple garments available for long duration missions. A system that can be used with regular crew worn clothing is desirable.

There was no capability to determine if an electrode had fallen off and the data recording had stopped. This required frequent verification that the unit was still recording data which presented a challenge with all of the other demands the crewmembers faced. The design of the EMG electrode connection to the wire harness needs to be reassessed. The software interface to verify the physiologic signals worked but could benefit from a more user friendly design.

This hardware is not yet ready for spaceflight. With further development and test evaluations on future NEEMO missions we are confident it can become a useful tool for physiologic data monitoring in space.

### **REPORTABLE OUTCOMES**

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The overall science results and final report on NEEMO 9 will come from the CMAS. The efforts by Dr. Broderick, supported through the grant received from TATRC have been covered herein.



Manuscripts on various aspects of this mission are in preparation and will be submitted the appropriate peer-reviewed journals.

The successful outcome of the NEEMO 9 mission, as well as others related research initiatives, has created a foundation for continued research in the area of telesurgery. The ability to remotely control a telerobotic surgical system was demonstrated.

## CONCLUSIONS

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Provision of emergency diagnostic and medical care in an extreme environment is of significant interest to the U.S. Army. Telesurgery has been identified by TATRC as a prime area of medical research for the next decade. This project has provided a tremendous opportunity to evaluate telesurgery and robotically-controlled surgical device in an extreme environment. The outcome of this effort will result in additional research with foci on telesurgery and robotic surgery. This work will lead to an eventual deployable telesurgery system that can improve the access to and quality of care in the battlefield.

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## **APPENDICES**

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## **Appendix 1**

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## Appendix 2

### **Acronym / Symbol Definition**

ARC	Ames Research Center
BMIST	Battlefield Medical Information System-Tactical
CODEC	Coder / Decoder
CPOD	Crew Physiological Operation Device
CMAS	Center for Minimal Access Surgery
CSA	Canadian Space Agency
CSI	Center for Surgical Innovation
DARPA	Defense Advanced Research Projects Agency
ELAN	Extended Local Area Network
IP	Internet Protocol
Kbps	Kilo bits per second
Mbps	Mega bits per second
NASA	National Aeronautics and Space Administration
NEEMO	NASA Extreme Environments Mission Operations
NOAA	National Oceanographic and Atmospheric Administration
NSBRI	National Space Biomedical Research Center
NURC	National Undersea Research Center
SRI	Stanford Research Institute
TATRC	Telemedicine and Advanced Technology Research Center
UC	University of Cincinnati



## **Appendix 3**

### **NEEMO 9 Crew Report**

# NEEMO 9 Crew Report



**Prepared by the NEEMO 9 Crew  
2006**

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Dave Williams, N9 Commander

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### **PATCH DESCRIPTION**

The NEEMO 9 mission and patch uniquely joined space and sea exploration. As NEEMO 9 was the first NEEMO mission focused by the new exploration vision, planetary exploration is emphasized by a rocket launching in a flash of red to travel from the Earth to the Moon, Mars and beyond. Sea exploration is emphasized by an aquanaut diving in a multicolor blue ocean under the silhouette of the Moon. The themes are subtly tied together by nine stars representing both the constellation Aquarius and the undersea Aquarius habitat in which the mission was conducted.

Over the months preceding this mission, the University of Cincinnati Design, Architecture, Art and Planning (DAAP) School designed this patch with input from the NEEMO 9 crew and topside team. The UC design team included Oscar Fernandez, Associate Professor of Digital Design; Hans Schellhas, a graduate associate; and crew member, Tim Broderick.

## **INTRODUCTION**

Building on the success of the NEEMO 7 mission in October 2004, NEEMO 9 evaluated the latest medical diagnostic and therapeutic technologies for the delivery of state-of-the-art medical care in remote and harsh environments. In addition to the telementoring and telerobotic surgery objectives, this space-analog mission included a number of research objectives to support the vision for space exploration and the return of humans to the Moon.

NEEMO 9 was a joint project involving McMaster University's Centre for Minimal Access Surgery, the U.S. Army Telemedicine and Advanced Technology Research Center (TATRC), the National Space Biomedical Research Institute (NSBRI), the Canadian Space Agency (CSA), NASA and NOAA/NURC.

The 18 day mission was broadly divided into telehealth and space exploration research. Telehealth research assessed protocols to deliver remote medical care and a prototype next-generation surgical robot. Surgeons in Hamilton, Ontario performed remote surgical procedures using the robot and a patient simulator in the Aquarius undersea laboratory, 19 meters underwater off the Florida coast, some 2,000 kilometers away from Hamilton.

While all of the scientific experiments conducted over the 18 day mission had direct applications for space exploration, a subset of the scientific experimentation were designed to answer specific surface exploration questions. Crew members performed a number of specific navigation tasks similar to those required by future lunar astronauts. They also used a remotely operated vehicle (ROV) controlled either by the crew inside the habitat or the ExPOC control center at Johnson Space Center in Houston to determine the optimum techniques for efficiently recovering simulated lunar specimens from an area around the habitat. The ROV was used alone and in conjunction with crew members walking on the seafloor in a manner similar to planetary spacewalks to locate simulated lunar specimens. Once recovered to the habitat, the simulated lunar specimens were sorted using the surgical robot in order to evaluate the potential benefit of a multi-purpose robotics platform for lunar habitats. Crew members were also weighed out to simulate Lunar and Martian gravity and performed surface exploration tasks to assess the optimal center-of-gravity of future planetary suits.

Lessons learned during the NEEMO 9 mission will continue to help us prepare for planetary exploration.

## **ACKNOWLEDGEMENTS**

As in the case of a space flight, a tremendous number of talented individuals from many different organizations work hard together to successfully accomplish something as unique and valuable as a NEEMO mission. All of the members of the crew experienced first hand the operational and scientific challenges of the mission, with the excitement and spectacular beauty of exploring one of the Earth's final frontiers. Each mission day we felt the support of the investigators, mission managers, and topside teams through our interaction with mission control in Key Largo and Houston. We would like to acknowledge the outstanding efforts of everyone that contributed to the mission. All have our heartfelt gratitude.





## **MISSION OVERVIEW**

The primary mission objectives for NEEMO 9 were to evaluate exploration enabling medical technologies, to assess spacewalking techniques for planetary exploration, and to conduct scientific experiments assessing human performance throughout the 18 day mission. The longest of all the NEEMO missions, N9 provided a unique opportunity for investigators from the NSBRI to use spaceflight research protocols to study changes in circadian physiology, crew compatibility, and individual behavior. N9 originated as a continuation of the very successful N7 mission in October 2004 that evaluated novel telehealth technologies and protocols for delivering remote medical care.

This mission demonstrated the tremendous benefit of interdisciplinary collaboration between government institutions, the academic community and the private sector. Led by the NASA NEEMO program, the Mission Management Team (MMT) included representatives from the Center for Minimal Access Surgery (CMAS), the Canadian Space Agency (CSA), the U.S. Army Telemedicine and Advanced Technology Research Center (TATRC), and the National Space Biomedical Research Institute (NSBRI).

The commercial payload represented a combination of telehealth experiments from CMAS and the University of Nebraska evaluating surgical robotic technologies. The M7 surgical robot developed by SRI was used to demonstrate real time telerobotic surgery between St. Joseph's Hospital in Hamilton, Ontario and the Aquarius undersea habitat with signal delays of 400 ms over a distance of 2600 miles. The latency of the signal was intentionally increased to 2 seconds to simulate lunar signal delays and assess the viability of telerobotic surgery for future lunar missions.

## **MISSION DESIGN**

In planning the mission, the Mission Management Team (MMT) developed a timeline that would meet the planned exploration and scientific objectives. An 18 day mission was chosen as it provided the necessary duration to achieve mission objectives within the scope of the resources available. Longer NEEMO missions may be considered in the future if sufficient personnel and financial resources are available.

The mission payload included 23 scientific and exploration objectives conducted both within (IV) and outside (EV) the habitat. EV activities were conducted with the crew using either the NURC supplied technical SCUBA diving rigs or a Kirby Morgan Superlite 17 helmet using a habitat gas supply. EV capability also included a rover configured to be operated in the free flying mode as well as a driving mode. Diver tracking systems and underwater mapping/navigation capabilities were provided to support the lunar exploration test objectives.

The 12 scientific objectives/experiments were selected through a peer review process and approved by the Johnson Space Center HRMRB as well as the IRBs at St. Joseph's Hospital, McMaster University in Hamilton, Ontario; the University of Cincinnati in Cincinnati, Ohio; and US Army TATRC in Frederick, Maryland. The 11 exploration objectives were identified by NASA investigators to provide operational data of relevance to future lunar missions.

Crew payload training was provided in both Hamilton and Houston in 2005 to support the mission, which was originally scheduled for October 2005. Hurricanes Katrina and Rita resulted in minor damage to the Aquarius habitat requiring the mission to be rescheduled in April 2006. Refresher payload training was provided in March 2006. Pre-mission dive training took place in Houston in the summer 2005, spring 2006 and in Key Largo in the week prior to the mission.

Crew selection was done by the astronaut office and approved by the MMT. Selection of the habitat technicians was done at NURC. All training and mission activities were reviewed and approved in a training readiness review conducted within the astronaut office.

## **MISSION SUPPORT**

In a manner analogous to spaceflight mission control (MCC), mission support was provided by teams working in Key Largo and in Houston. Working at the NURC facility, the NEEMO 9 topside team in Key Largo included representatives from NASA, CMAS and the NSBRI. NURC staff provided continuous mission support for the Aquarius systems and saturation diving throughout the mission. Mission medical support was provided by the U.S. Navy and NASA with a diving medical officer (DMO) on site at NURC and experienced flight surgeons (FS) at Johnson Space Center in Houston. The Exploration Planning and Operations Control (ExPOC) at Johnson Space Center provided operational support during the simulated planetary spacewalks, remotely controlled the rover in both free flying and driving modes, and enabled lunar geologists to evaluate telescience protocols using a remotely controlled robot to sort simulated lunar specimens.

Overall, as with so many other things about this mission, we felt that our topside support was excellent. Our topside team was made up of several different groups that were all very obviously committed to the success of the NEEMO 9 mission and to the needs of the crew. As in the case of spaceflights, the duration and complexity of the NEEMO 9 mission resulted in a number of hardware failures, timeline pressures, re-planning efforts, equipment troubleshooting, and medical issues that provided a variety of “learning opportunities” that could have easily challenged the ability of a lesser team to succeed. As a crew, we felt that all of the operational challenges we faced were handled appropriately as a joint topside/undersea team. Within the means available to the mission, we were provided with the necessary support to ultimately ensure success.

We recognize that it takes the involvement of a number of different groups working together to succeed with this type of mission. Ideally, the division between the different support groups should be transparent to the crew. As far as the crew is concerned there should be only one topside team. We suggest that more integration is required between the different support groups --- in particular between the NASA DT/CB and ExPOC groups. Integration of these two groups, especially from the standpoint of day-to-day implementation of the timeline, will result in a more efficient and effective implementation of the plan. A convenient model to initially follow would be that of an ISS Increment team (e.g., Lead Flight Director with a hierarchy of all the supporting groups reporting through them and the crew using a single communication link to topside via a “CAPCOM”).

We understand that the Habitat Technician crewmembers also have a chain of command and communication protocol that they use that is independent of the core mission operations interface. This interface is required for them to maintain the safe operation of the facility.

***Recommendation 1: Take all necessary steps to ensure that the entire topside contingent works together as one seamlessly integrated team. Improve communication between all members of the topside team and ensure all necessary personnel are working together in a coordinated manner with all mission activities. Eliminate multiple points of contact between the crew and topside team.***

We would like to thank our topside support for recognizing how positively the “little things” can provide behavioral support and positively affect a crew. These “little things”, which might have seemed insignificant to an outsider, were both individually and collectively very significant and appreciated by all of the crew. These are things that take additional topside time and require special attention to the personality of the crew. We’re very happy that the topside team took the initiative to be proactive with the “little things” throughout the mission. Some of the things that come to mind are: the peanut butter cookie “cargo”, the Easter basket and individually selected cards, quotes of the day that were strategically picked from a DPC or other day’s events, the song from our ExPOC co-ops, sending topside reports to our family and friends, another bag of tortilla chips, hosting our families at ExPOC and doing all the work to make them feel welcome, ensuring that all of our mission pictures were saved, welcoming our families for splash-up, laughing with us during creativity session #2, etc, etc. These all helped make the mission more fun for the crew and hopefully for the topside team members too.



## **NEEMO AS A SPACEFLIGHT ANALOG**

The NEEMO mission has been described as the best training exercise to prepare crew for space flight. This contention is definitely true, but a NEEMO mission is much more than a training exercise. The NEEMO missions are just that: Missions. As such, these missions and the Aquarius habitat provide an excellent test bed to prove procedures and technology that support the Vision for Space Exploration. These are true missions with substantial scientific objectives in and of themselves.

Key aspects of NEEMO as a space flight analog include:

- The crew must live and work in a small isolated environment where they must rely on their life support systems to survive.
- In the event of an emergency an immediate return to the surface of the Earth is not an option.
- The timeline and timed activities closely resemble those of a space flight and is probably not unlike what we can expect on the preliminary lunar expeditions.
- The pressure that the crew experiences executing an aggressive timeline knowing that PI's that have devoted a great deal of time as well as significant

resources to the experiments and are counting on the crew to produce data that can not be duplicated in a simulator.

- Undersea EVA's are conducted as if they were space-based EVA's.
- Mission Control (ExPOC and NURC) is incorporated in a manner consistent with spaceflight.
- Every science activity and EVA was mapped to specific exploration objectives. These objectives were assigned an exploration scenario and broken into two distinct areas: Exploration Objective (What we want to learn for space exploration) and NEEMO Analog Objective (What we want to learn to improve the next NEEMO mission). This comprehensive matrix can be found in Appendix 8. Laminated copies of these objectives were stored and accessible in the wet porch for review prior to every EVA and science activity.

To ensure that the mission was conducted as close as possible to an actual spaceflight the following expectations listed below were established pre-mission.

## **NEEMO 9 GENERAL EXPECTATIONS**

### **CREW:**

- Accomplish the timeline activities on time, and as efficiently and effectively as possible
- Treat the mission as a spaceflight for the entire mission duration
  - o Have an operationally realistic communications plan – the crew will only use the cell and IP phones for emergencies.
  - o Plan and execute activities outside the habitat in a manner similar to spaceflight EVAs.
  - o Be prepared for all potential safety contingencies.
  - o Adequately prepare for all activities.
  - o Attain and maintain an appropriate level of fitness to participate in mission activities.
- Document all NEEMO and Exploration Lessons Learned (Through lessons learned database and photo/video documentation)

### **TOPSIDE TEAM:**

- Provide an operationally relevant set of mission objectives to contribute information of relevance to future NASA space exploration that will be documented as lessons learned in the exploration database.
- Be accessible to the crew for operational mission support.
- Provide crew all required equipment and procedures in a timely manner. (Sufficient time for the crew to prepare for each activity)
- Ensure all mission data provided by the crew (e.g., photos, video, journals, experiment data, etc) is safely backed up, and will be provided to the crew post mission.

### **ExPOC:**

- Provide MCC support as prime point of contact for crew during hours of timed ExPOC supported operations.
- Coordinate with the Topside team on all required issues/questions received from the crew.

- Develop all supplementary procedures and re-planning required for exploration test objectives and provide to the crew in sufficient time to prepare for each activity.

#### PI's:

- Treat the mission as though it's a spaceflight
  - o Except for timed communications (directly involved in experiments) channel all communication through the Topside team (Do not call directly to Aquarius).
  - o Be accessible to the crew for experimental support/questions (channeled through ExPOC or Topside team as appropriate).
  - o Provide crew required equipment and procedures in a timely manner (Sufficient time for the crew to prepare for each activity).
  - o Provide MCC support as prime point of contact for crew during hours of timed PI supported operations.

***Recommendation 2: The Crew and Topside support team should work together pre-mission to establish a working mission protocol for all mission communication responsibilities and operations.***

### **PREMISSION TRAINING**

#### Preliminary JSC provided SCUBA Training, Key Largo

This training included basic SCUBA diving techniques and buoyancy control, as well as an opportunity to see the NURC facility and meet the staff. Much of the training was conducted by the NEEMO topside team. All training was efficient and very professionally done. This is an excellent way for the crew to initiate a "bond" and to gauge the overall crew comfort level in the water.

The crew also participated in SCUBA diving at the NBL to practice their diving skills. The additional complexity of scientific diving requires a high level of comfort working underwater. Strong basic diving skills are a critical element in preparing crews to safely participate in NEEMO missions.

***Recommendation 3: If the preliminary JSC training at NURC is not possible for future crews, we strongly suggest scheduling crew dive training activities at the NBL. Practicing dive skills at the NBL should be done anyway, but more structured crew activities coordinated with the NBL divers would be very beneficial; especially in light of the reduced SCUBA that will be happening with several of the upcoming missions. Every effort should be made to ensure comfort level with SCUBA skills prior to participating in the pre-mission NURC training.***

#### JSC Training Week, Houston

This week again provides the crew with the opportunity to get to know each other better. This week was primarily used for familiarization with some of the procedures and equipment, timeline review, baseline data collection, experiment training, PAO and

Educational Outreach overview, etc. Based on the mission objectives, the overall content of this week will change, but the following are general recommendations:

**Recommendation 4: Provide the crew with a copy of the timeline for their review prior to this training week. This will help the crew be better prepared for the timeline review during the training week. The timeline review should include representatives from as many of the support groups as possible, and should include a discussion of the overall operations protocol.**

**Recommendation 5: Remove the briefing on the CB Expeditionary training flow from the schedule. All of the CB crew members participating on NEEMO will be familiar with this flow, and it has no impact on the non-CB crew members.**

**Recommendation 6: Continue to provide simplified standard practices for things like Photo/Camera Management. Each crew will appreciate having and will most likely work to this standard, and then will be able to modify as necessary during the mission.**

**Recommendation 7: Provide as much hands-on time with available hardware and the associated procedures as possible (to include training events like the CobraTac and camera practice we were provided).**

**Recommendation 8: Provide a scheduled meeting with the previous NEEMO crew. This was not a scheduled event for our crew so we arranged it ourselves. We only had an hour over lunch with a couple of the NEEMO 7 crew members, but it was very beneficial – a scheduled event will be even more valuable.**

**Recommendation 9: Provide a thorough Habitat overview including lessons learned from previous missions regarding stowage, computer setup, experiment setup, living arrangements and description of different modules. Although it does not cover all of these details, “Appendix 11, Living and Working on Aquarius” is a very useful reference and should be made available as soon as possible for future crews. Something like this would have been extremely useful for us. Other reference material such as the NOAA Technical Diving Manual and a textbook on scientific diving techniques should be available within CB.**

**Recommendation 10: Incorporate a crew dive session at the NBL. In addition to basic SCUBA skills, practice at the NBL with tools like CobraTac and the cameras. It should be easy to develop short scenarios for practice in the NBL with the CobraTac and taking pictures with the camera/strobe and video camera.**

#### NURC Training, Key Largo

The NURC staff provided excellent training in preparation for the NEEMO mission. The first day of the NURC training started with a swim test, which took place at a local pool down the street from the condo. The approach of the instructors was very relaxed, but they still have their requirements: 400m in 12 minutes – any stroke. This is to demonstrate that each crew member is at ease in the water and has no problems completing the swim. This was followed by 10 minutes treading water. The requirements also included a 25m underwater swim on a single breath. The NURC

instructors have some very helpful tips like taking 3 deep breaths before you plunge, using strong strokes and taking advantage of the entire glide you get from the stroke, and swimming along the bottom to minimize surface friction. It is a good idea to listen to their suggestions. The test finishes with doffing and donning a mask and snorkel on one breath in about 5 ft of water.

***Recommendation 11: Crew should practice the different swimming skills for the swim test and get comfortable with them before going to Key Largo. The support of the commander is very important in crew participation in fitness training prior to and during the mission. The ASCR team at JSC and the ARF may be used to help prepare crew members.***

The training schedule during the last week at NURC prior to splashdown was intensive. The bulk of the SCUBA skills training and payload training occurred during this timeframe. The long training days were mentally and physically exhausting for both the crew and the JSC Topside Team that supported this training. The SCUBA training was very professional and appropriately progressive through the week. This was an excellent training flow for establishing the crewmember's comfort level in the water, with the equipment, and for providing the NURC team with the opportunity to establish their comfort level with the crew. Anyone who goes through this training is guaranteed to have a new appreciation for SCUBA, and to see a significant improvement in their own skills. The training is very focused on the overarching safety issues associated with saturation diving: buoyancy control, buoyancy control, buoyancy control, and the surface is not an option.



This training was absolutely critical to the overall success of the mission. SCUBA skills that were required for the mission were developed and reinforced. Proper dive CRM and the ability to function in a task saturated environment can not be learned in a classroom. One of the key skills learned during this week is proper task prioritization. By placing aquanaut candidates in a situation where they cannot accomplish all tasks simultaneously they are able to learn the proper priority to drop tasks as necessary. For instance, buoyancy control is quite easy for even novice SCUBA divers, but when you couple buoyancy control with emergency buddy breathing, navigation, and unfamiliar equipment a diver must not allow buoyancy control to drop out of the crosscheck. This week of training did an excellent job demonstrating how fast buoyancy control can be undermined if constant attention to detail is not maintained.





EVA's conducted during the mission with SCUBA were extremely valuable to the overall exploration analog and crewmember's individual spaceflight training. The importance of having complete situational awareness (SA) of depth, vigilant monitoring of consumables is critical. Placing the crew in a situation where their safety depends upon maintaining proper SA and taking appropriate actions to a changing environment is what makes SCUBA such a valuable part of the NEEMO missions. Our NURC pre-mission training prepared us well to meet these challenges.



**Recommendation 12: All future NEEMO missions should include SCUBA-based EVA training and mission EVA's**

For the most part, the weekend prior to 'Splashdown Monday' was free of training. Most of the Topside Team left Key Largo on the weekend leaving the condo to the crew alone. This 'alone' time was used profitably by the crew to wrap up last minute affairs, to write crew notes and cue cards, to review procedures and the mission timeline. Dan, Alex and Kristen remained at the condo and were a great help as we scrambled to produce our laminated mission checklists and other mission materials.

**Recommendation 13: All crew training should be completed three days prior to Splashdown. The two days prior to Splashdown should be completely free of training to permit final mission preparation. However, this final mission preparation should not include putting the crew in a position of still needing to ensure procedures and other support materials are correct and complete. The preparation process for NEEMO missions needs to improve with respect to ensuring that the process adequately incorporates validation of all procedures and support material – the crew should of course be involved with this ahead of**

***time, but not responsible for ensuring it is complete – this is the role of the topside support team. The weekend before splashdown should simply be a time for the crew to relax and review the plan for their mission.***

## **MISSION OPERATIONS**

### **Safety**

An appropriate emphasis was placed on safety in all aspects of mission training and operations. Saturation diving has the potential for significant, possibly life threatening, consequences if appropriate procedures are not followed. The NASA and NURC training team did an outstanding job in preparing the crew for both the SCUBA and Superlite diving while saturated.

The crew developed specific pre-dive checklists for both SCUBA and Superlite diving and these checklists were used prior to each dive. Post-dive debriefs were conducted after the dives. When switching between the SCUBA and Superlite diving it is important to review the appropriate equipment and protocols used in addition to the standard dive briefings. The pre-dive briefs for unique dives such as the dawn and night dive should include additional information specific to the dive conditions. Crew should be encouraged to ask questions if they are unsure of any aspect of the dive objectives, hand signals, diver recall or emergency procedures.

Underwater navigation is critical for saturation diving and the impact of getting lost is significant. To facilitate situational awareness the N9 crew had laminated bathymetric maps of the reef surrounding the habitat that showed the position of all excursion lines and their compass headings to and from the habitat. These were used in the pre-dive briefing to enhance situational awareness on the location of the habitat relative to the dive site and the approach to follow for lost excursion lines or lost divers. To minimize the risk of a lost excursion line the N9 attached a cave reel to the excursion line each time they left the excursion line to conduct activities on the reef.



Mark 48 communication masks were used throughout the mission for SCUBA activities. The N7 crew had identified a problem with intermittent mild shocks from the microphones in the Mark 48 mask during their mission which recurred during the pre-mission training for N9. The response of the NURC team was outstanding in resolving this problem. Within 24 hours new microphones were installed in all of the Mark 48 masks which eliminated the problem and gave better performance than the previous microphones. This response was typical of the outstanding NURC mission support and attention to safety.



Similar shocks were experienced by some crew members while using the Superlite helmet during pre-mission training and diving during the mission. Once again the NURC team was very aggressive in responding to the problem and spent a considerable amount of time troubleshooting the problem. While a number of the changes made seemed to solve the problem it ultimately recurred intermittently on subsequent dives. Dives were terminated when the problem was encountered with further troubleshooting implemented before subsequent dives. Ultimately all Superlite dive objectives were accomplished. This anomaly remained unexplained at the end of the mission and will be worked by NURC prior to any further NEEMO Superlite diving.

#### Timeline, mission management tools – OSTPV, IPV

Mission management tools included the OSTPV and IPV software packages currently used by space station crew. In addition to these electronic tools the crew had a printed version of the timeline that was updated after each daily planning conference (DPC). The paper version of the timeline was frequently used if the computers were in use for other reasons. The electronic version worked well. The greatest limitation was the need to have access to a computer. This could be alleviated by having more computers available or by having a version of the software that could be used on an IPAQ.

As is frequently encountered during a spaceflight, significant re-planning was required on a daily basis due to hardware and experiment issues. The topside team did an outstanding job with the daily re-planning efforts and changes were incorporated into OSTPV in a timely manner. The actual mission timeline was quite different than the planned version due to the re-planning efforts and accurately reflects the challenges experienced during spaceflight mission planning.

Use of IPV was attempted several times at the beginning of the mission, but the software was never functional and therefore IPV was never used during the mission.

#### Daily Planning Conferences (DPCs)

DPCs were conducted twice a day throughout the mission and were a critical element of mission success. The ability to communicate real-time with mission control about the issues confronted during the day allowed the topside team to work the issues, re-plan the timeline as required and send the crew new procedures for experiments or IFMs. The majority of the time these were led by the N9 Commander with the remainder of the crew participating as well as the NASA/NURC topside team and the ExPOC.

#### Private Medical Conferences (PMCs) and Medical Events

PMCs were scheduled twice during the mission at weekly intervals allowing the Commander and/or CMO to speak with the Navy DMO and NASA FS. The Navy DMOs changed halfway through the mission and each of them was able to dive to the habitat and visit with the crew. Though not similar to what would be possible during a spaceflight, these visits enhanced the rapport between the crew and DMO and were very helpful.

There were no significant medical events during the mission. There were a number of minor medical issues typical of NEEMO missions that included skin lesions, a minor case of otitis externa and abrasions. During pre-mission training a number of the crew experienced symptoms of upper respiratory congestion at night the exact cause of which remains to be determined. Some crew found that the symptoms seemed to be related to sleeping in the bunk room, but a causal relationship was not clearly established. These symptoms impacted pre-mission dive training, but did not prevent the team from following the training template.

One of the crew developed an infected epidermal inclusion cyst prior to the mission that was treated with oral antibiotics after spontaneous drainage. It was decided by the DMO, Commander, CMO, NASA and NURC team leads that there would be no unmanageable adverse medical consequences to having the crew member participate in the mission. Treatment continued in saturation and the lesion healed successfully without complications.

There were no infectious illnesses in any of the crew, nor were there any injuries that impacted training. While there has been no policy on establishing a quarantine period prior to the missions similar to spaceflight, the crew was aware of the risk and maintained an aggressive approach to hand washing and avoiding close contact with individuals with that were sick.

***Recommendation 14: Due to the potential mission impact of illness immediately prior to the mission, the Space Life Sciences Directorate should be consulted to determine what type of quarantine and primary contact (PC) program would be reasonable for a NEEMO mission. The program could be as simple as having the crew use hand sanitized frequently and having a voluntary PC program that reduces contact between individuals that are ill and the crew. PC physicals of individuals in contact with the crew may not be necessary.***

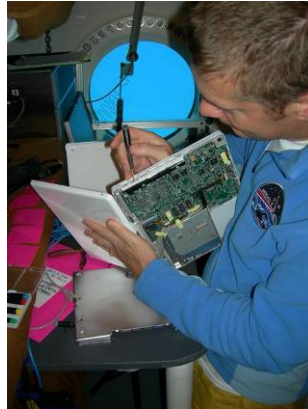
Approximately three weeks prior to the mission the Commander was medically disqualified and the back-up Commander was assigned in his place. Changes to the crew close to a mission can be difficult, but the crew adapted well and was able to come together as a team during the pre-mission training.

***Recommendation 15: Having at least one or two back-up crew members available for NEEMO missions is worthwhile. This was the second NEEMO mission in which a Commander was medically disqualified within weeks of the mission. In addition to multiple backup crew members, there should be an increased participation in training activities by the backups.***



## **COMPUTERS**

### **General comments:**



Basic computer hardware and software familiarity proved important during this mission. Most of the crew members had the IT skill and the comfort required for proficient use of standard NASA mission management tools. NEEMO topside training was concise, high quality, and allowed successful use of such tools during the mission (e.g. OSTPV, IPV and JEDI).

In addition, basic IT skills facilitated successful client-server desk top use. The thin clients within the habitat that were connected to the NURC server during this mission proved easy to use and beneficial. Thin client training by NURC staff during the training week and at the beginning of mission was appropriately short and functional.

Use of multiple different laptops, CODECs, and controllers in the exploration and telehealth science payloads introduced mission complexity and challenge. Significant IT expertise was required to define problems and subsequently configure working solutions within exploration and telehealth research. Significant crew familiarity with different types of computer hardware, operating systems and network communication proved invaluable.

Crew access to subject matter experts with specific expertise in exploration or telehealth-related hardware/software was important. Application and/or network failure during integrated use of technologies distributed across sites confirmed the need for appropriate IT expertise specific to each component technology and each site. For example, during remote control of the Outland rover from ExPOC to Aquarius using the Internet, Brian provided technical support regarding the rover, network administrators provided access through their respective firewalls, and end users altered/ran software that resulted in eventual success.

Wireless networks were not used in habitat by crew and could be further explored in future missions.

***Recommendation 16: The NEEMO program should have sufficient resources to incorporate similar technologies in Aquarius to those used on the Shuttle and Space Station. The availability of A31P computers with wireless networking***

***capability would reinforce for crew the IT skills required for spaceflight. A PGSC plan similar to that used in Shuttle missions would be of benefit for NEEMO.***

NEEMO 9 computer hardware:

- 1) Three NEEMO laptops (Nedland (Dell), Arronax (Dell), and Kapoga (IBM))
- 2) Three thin clients (to NURC server)
- 3) Four IPAQ PDA (with keypads)
- 4) CODECs (Polycom, VBrick, Haivision)
- 5) Three 1 Gb thumbdrives
- 6) Exploration
  - a. LinkQuest
  - b. Cobra-Tac
  - c. Outland rover controller
- 7) Telehealth
  - a. CMAS Apple G4 laptop and amplifier
  - b. Sonosite ultrasound
  - c. SRI M7 slave controller and arms
  - d. Handshake haptics computer and Omni Phantoms
  - e. UN In Vivo Robot controller

IT Problems encountered:

- 1) Arronax serial port not working throughout mission
  - a. Inability to remotely control Outland rover with Arronax
  - b. Eventually found to be secondary to problem with software conflict (com1 use by IPAQ ActiveSync)
  - c. Crew unsuccessfully attempted to correct to relieve Nedland conflicts
- 2) Inability to successfully configure Kapoga for Outland rover use during mission when sent as back-up.
- 3) IPAQs with poor usability secondary to small screen size and keyboard with poor ergonomics. Therefore, IPAQs only used for journal entry. Single crew member also used his IPAQ to listen to music.
- 4) Cobra-Tac downloaded slowly at beginning of mission as matched to set speed of Nedland. Subsequent concurrent increase in laptop and Cobra-Tac download speed increased rate of transfer. Download procedures require further clarification as described in separate exploration section.
- 5) Telehealth
  - a. G4 laptop port failed with minor spill of EEG electrolyte solution onto keyboard. The laptop was replaced days later after new laptop purchased and configured. Amplifier subsequently failed and could not be replaced. Single point failures limited data acquisition.
  - b. "Blue screen of death" on Nedland during use on CMAS1 suggested I/O issue. Workable solution was arrived at during mission by reconfiguring Nedland IP address each time it was used for this experiment.

***Recommendation 17: Individual SD memory cards should be provided to each crew member with an expansion slot for the IPAQs. This provides a mechanism***

**for each of the crew to bring digital photos of their family and a personal selection of music as behavioral support tool during the mission**

**Recommendation 18: Crew members should have a basic familiarity with computers and information technology. In more complex, longer duration missions, more advanced IT skills in at least one crew member is desirable.**

**Recommendation 19: Access to IT expertise within topside, NURC and collaborating academic/industrial partners during mission is critical. Access to topside experts should follow established protocol (via “MCC”) to insure exploration analogue.**

**Recommendation 20: Thin clients and large storage size flash drives should be used on future missions. This combination is especially useful when large file transfer and data backup is required such as in photo management. Each crew member should have at least a 1 GB USB flash memory stick for file transfer during the mission.**

**Recommendation 21: Upgrade computer hardware as funding permits.**

- a) Select standard laptop (IBM A31P) for multipurpose use based upon optimal combination of speed, storage, I/O ports, and ruggedness. Standard laptop will remove conflict of use, facilitate trouble shooting, and allow easy replacement in case of failure. As funding permits, at least two identical laptop computers should be configured with identical mission, exploration, and science software for use in Aquarius. An additional laptop should be available topside to assist with troubleshooting and to serve as replacement laptop if needed during mission.**
- b) Consider upgrading IPAQs to tablet PCs for individual crew member use. If IPAQs cannot be upgraded, we do not recommend continued use of individual PDAs during mission. Journal can be typed on laptops or thin client. Nano IPODs can be used to listen to music as needed.**
- c) Use of standard laptops without IPAQs also will decrease supporting equipment such as chargers, com adapters/cables, portable keyboards, etc.**

**Recommendation 22: Use standard software on all laptops to decrease familiarization/training, simplify procedures, improve troubleshooting, and provide redundancy. Remove all unnecessary files, software, viruses, spyware, etc. before departing for Key Largo. However, ensure all data from previous missions has been saved before software removal.**

**Recommendation 23: Confirm consistent, expected performance of hardware/software before departing for Key Largo.**

**Recommendation 24: Encourage investigators to use standard NEEMO hardware/software. If not feasible, critical science computer should have back-up either in habitat or NURC base.**

**Recommendation 25: As much as possible, all familiarization and training should be done on standard laptop in mission configuration.**

**Recommendation 26: Consider greater use of wireless network in future missions (80211.g, 80211.n and Bluetooth). Use of the wireless network in the habitat would allow hardware use at the point of need and avoid long Internet cables that present risk to crew and hardware. In addition, wireless would decrease hardware and personnel crowding by jacks in the entry lock and bunkroom.**

### **Photo/TV**

#### **Still Photo Management:**

Management of still photos was pretty straight forward. We found that it worked well to have one crew member managing the photos, with everyone picking up a camera and taking pictures as often as possible to cover as much of the mission activities as possible.

The bulk of the photo management tasks were performed in the evening during pre-sleep. Tasks included:

- Setting up a folder for each Mission Day (MD). We chose one of the laptops (NedLand) for storing all still photos. Within each MD folder were subfolders for “Best of”, “In the Habitat”, “Dive ops”, and “Experiment specific ops”; as well as subfolders for any special events, e.g., Easter. We tried to do our best to file all of the photos into the different subfolders at a level that would make sense, but wouldn’t require individual labeling of each picture.
- Downloading each MD’s pictures to the subfolders on the laptop. This involved collecting the memory cards from each of the still cameras (we had 3 digital cameras: 2 NEEMO provided – 1 Canon and 1 Sea & Sea, and Dave brought his personal Olympus), copying all pictures from the memory cards and sorting them into the subfolders, and selecting the “best of” for the day (this was done with input from all crew members). We also chose to backup all photos on a thumb-drive in addition to storing them on the laptop. Multiple thumb-drives were needed to maintain a complete backup of all the pictures.
- Transferring the MD folder to the NURC server for retrieval by the topside team. This was an excellent and very quick process of taking the thumb-drive and plugging it into the NURC thin client to copy the photos to the server.
- Clearing all pictures from the memory cards (once we were comfortable they were safely stored on NedLand, a thumb-drive, and the server), to prepare the cameras for the next day.
- Removing batteries from the cameras and strobe for charging; and replacing with fully charged batteries in preparation for the next day. We would also inspect the camera housing, and clean and grease the o-rings as necessary.

We really didn’t have any requirement for editing pictures during the mission, with the exception of resizing selected ones for our own use in emails or journals. This was made extremely simple thanks to Dan Sedej setting up a resizing shortcut on the computer for our use.



The cameras themselves were also fairly straight forward, but we would still recommend as much hands-on time with them as possible prior to mission use. It takes a little time to get the hang of using the strobe (which by the way is a beautiful tool to have) for taking clear in-water shots. Also, there are a variety of challenging interior shots (e.g., through the view ports, when to use a flash or not, minimizing overexposed shots, tight quarters). Dave came up with an improvised little diffuser for use with the Olympus and Canon cameras that seemed to help; the easily accessible menu options on the Olympus were very helpful for different shots; using the Sea & Sea camera inside with the wide angle lens and strobe; and the small tripod were also helpful.

We were very diligent about the way we handled the in-water camera operations, especially to ensure that we did not flood the camera. We performed a freshwater bubble check before every dive; we never went above the viewport depth with the camera (however, this would have been a risk to violating our own depth excursion limits so we never did it); always rinsed the housing in freshwater after each dive; and always inspected the housing and cleaned and greased the o-rings as necessary at the end of each day. To ensure we didn't risk the batteries dying during a dive, we did not use the preview function on the camera.

For additional details regarding camera operations and lessons learned, please refer to Appendix 5, which contains a summary of the debrief questions compiled by Dan Sedej.

***Recommendation 27: If time is allotted in the schedule for photo management, it should be at the end of the day. Otherwise the crew will do this during their pre-sleep timeframe.***

#### Video:

Due to the requirements of the science activities on this mission a substantial amount of video was shot and potted up to the surface (approximately 60 hours of recorded video). A video shot list (Appendix 6) was produced permission to supplement the science video requested from the PI's. This video shot list was hung in the entry lock behind the computer used for OSTPV so that we could keep track of what shots were accomplished and what still remained. In order to keep track of all the recorded tapes we assigned a tape number to each cassette and used a standardized label format to annotate the date, mission date, experiment number, and contents of the tape. This information was expanded and recorded in a video shot log that was kept in one of the crew notebooks (Appendix 7). About 45 minutes was spent at the end of each day to annotate the video tapes and video log and prepare the tapes for shipment to the surface (This time was not accounted for on the OSTPV crew timeline). We kept separate tapes with us for the duration of the mission that we used for various purposes (documenting exploration lessons learned, Saturday morning science etc.).

The Sony camcorder was the only camera that we used with the underwater rig. The operation of the Sony was straight forward. One potential concern is the mode switch on the side of the rig. If the mode switch is inadvertently bumped, the camera could switch from tape mode to memory mode. We could not determine a method to check which mode you are in while the camera is in the rig underwater. If in doubt simply cycle power and the camera should reinitialize in the tape mode. All video should be recorded in tape mode which records on the DV tape. If the camera records on memory

mode it records low quality mpeg images on the memory stick. As with the still camera a thorough bubble check is required to ensure the camera does not get flooded.

We had several different types of video cameras to use within the habitat. By far the Sony camera was the camera of choice. The quality of the images on the Sony camera is significantly better than any of the other cameras we used. We also used the Sony camera during our education outreach and PAO events. The Sony camera has an S-video port that we connected directly to the Polycom unit. We could then select between the Polycom camera (for a wide overhead shot) and the Sony (for views out the view port, crew close ups, and habitat tours). We elected not to make a recorded habitat tour for our education events. Instead we conducted a live tour during each one of the events. The advantage of this is you get a wider range of activities to show the students (EVA prep, IVA activities, ROV activities etc.) The down side is you're stuck with whatever happens to be scheduled during the same time as the event. If you are going to do a live tour realize that the power cord is not long enough to travel throughout the habitat (the S-video cord is long enough). Since the power cord is not long enough when you pull the cord and go on battery you will lose the picture momentarily. Either warn the audience that you are going to lose the picture for a moment or conduct the entire event on battery power.

**Recommendation 28: Increase the number of Sony cameras to at least three and use for all activities requiring video documentation**

**Recommendation 29: Include about 45 minutes in the crew timeline at the end of the day to accomplish video tape administration**

### **ExPOC Support**

In general the ExPOC support was excellent. The incorporation of a mission control center adds a great deal to the exploration analog and the ability to capture exploration lessons learned. The maturity of the NEEMO program warrants a change in philosophy from viewing the missions as exploration analog training to actual exploration enabling science missions. With this shift in philosophy ExPOC will need to take an expanded role in future missions.

**Recommendation 30: Fully integrate the topside (JSC NEEMO) team with the ExPOC team into one functional team that communicates in such a manner that's seamless to the crew. (See also recommendations 1 and 2).**

**Recommendation 31: Incorporate a NEEMO CAPCOM that is the sole individual to communicate with the crew during ExPOC/Topside Team supported operations. Ideally this CAPCOM should be an astronaut who is a previous NEEMO crewmember or one of the back-up crew assigned to the mission.**

**Recommendation 32: The integrated ExPOC/Topside Team should treat all future NEEMO missions as actual exploration space flights. Specific recommendations are:**

- a. The Topside team should function as ONE team --- one team that just happens to consist of a control center (ExPOC) and local***

**support (NASA/NURC topside in Key Largo). Integration is key for maximizing SA for everyone and for maximizing effective communication with the crew.**

- b. Research all of the crew's technical questions that arise during the mission and formulate a timely response after conferring with experts (as opposed to suggesting that the crew contact experts directly).**
- c. Establish and follow flight rules for all exploration activities.**
- d. Establish and follow certification requirements for specific ExPOC control room positions and activities (i.e. ROV ops, CAPCOM, etc.) and provide the associated training.**
- e. Develop and communicate a fully coordinated plan for each day's activities. Ensure that these plans are fully coordinated with all members of the topside team to include the NURC staff. Do not ask the crew to plan the following day's activities during their pre-sleep activities**
- f. Adhere to strict console communications protocol that follow operational space flight protocols including:**
  - Never leave the crew without a quick response to comm. Therefore, never leave the console unattended, and be prepared to drop all other conversations when the crew calls and respond immediately to them. The crew should never wonder if there is someone on the other end of their call.**
  - If you don't have an immediate answer to a crew question, there are 2 possible responses:**
    - "Stand by" – means you know you can get the answer quickly enough that you're expecting the crew to stop what they're doing and "stand by" for your answer before proceeding.**
    - "We'll have to get back to you" – means that you will have to go track down an answer and it's going to take some time. In the meantime, you will need to provide the crew with feedback on how to continue the task without the answer or to redirect the crew to another task.**
  - Clear repetition of call signs and slowly spoken call details or response.**
  - Anticipation of crew questions/responses based on task being performed (e.g., GCA task to find transponders --- know what GCA means and that the crew is going to expect you to be proactively providing it).**
  - Based on SA, know if it is likely you'll get a response from the crew when you ask them to repeat or if it's even important enough to ask the crew to repeat.**
- g. Ensure all topside members are fully aware of the crew timeline and the impacts of checking-in late for planned DPCs and/or not being prepared to discuss the plans for the day**

- h. Record all data being collected to include video feeds and transcripts of transmitted data points (even if the crew is also recording the data).***
- i. Adhere to the 5 P's (Proper Planning Prevents Poor Performance)***
- j. Always strive to be at least one step ahead of the crew.***
- k. Anticipate questions and have the answers ready. (This will require previous review and study of the procedures the crew will be implementing).***
- l. Have all the supporting information available to support crew implementation of the task (especially in situations where the crew can't have these in front of them themselves, i.e. out on a dive).***
- m. Know the task – for all procedures know who does what and why (e.g., where we had some problems with the ROV procedure).***
- n. Have all procedures open on console and actively be following along with the crew.***
- o. Know who the experts are and be able to contact them quickly for support (ideally they would be supporting on console too).***
- p. Situational Awareness is key!***
- q. Know the limitations/overhead associated with the equipment the crew is using (e.g., ptt button on comm masks; swimming with the CobraTac; cave reel ops...)***
- r. Know all the “knowns” about the territory the crew will be operating in (e.g., excursion lines; approximate bearings/ranges associated with all known features...).***
- s. Know dive operations/safety limits and how what you're asking the crew to do impacts them (e.g., picking up and carrying heavy weights; replanning a dive in the middle of the dive...)***
- t. Establish and operate within “flight” rules. All of the above examples fall within this category of flight rules, as well as things like operator qualifications for ROV ops.***

### **Media and PAO Opportunities**

The N9 mission attracted considerable media interest throughout both the United States and Canada. It is clear that there is significant public interest in space exploration activities. Some of the media highlights included coverage by Canadian national TV, Good Morning America and Popular Mechanics.

NEEMO missions are an excellent opportunity for educational outreach and PAO events. If you have schools or hometown media you want involved with the mission, be sure to provide them early. You may also need to be proactive and persistent about whether or not these schools/media are being contacted with the information about how to participate. Don't assume that they will be given priority for events, or that anyone is specially trying to contact them for you.

### **Educational Outreach**

A number of interactive educational events from elementary through the collegiate level were conducted throughout the United States and Canada during the mission. Crew

members supporting the events gave an overview of the mission, a video tour of the habitat and answered questions for the students.

The crew was also able to perform a science experiment submitted by students at Mount Carmel School in Houston. This experiment has led to improved anti bacteria protocol for long duration NEEMO missions and generated a great deal of positive media attention.

**Recommendation 41: Crew requests for media, PAO, and educational outreach activities should have priority when the schedule of events is established for the mission.**

### **PRIVATE FAMILY CONFERENCES**

The opportunity to hold 2 video conferences with our families during our 18 day mission was greatly appreciated. We think this was a valuable option to have from both our and our families' standpoint. The crew member and their family should be free to decide whether they want to participate in these video conferences or not. Another form of communication (e.g., phone) may be less stressful for some families.

**Recommendation 42: Continue to offer the opportunity for video conferences with our families. However, recommend we just call them Family Videoconferences, not Private or Personal Family Conferences (PFC). There is no way for these to be private and we shouldn't give the families the impression that they are.**

**Recommendation 43: Your Habitat Technicians are members of the crew and have families too. Include the videoconference option for them as well and make sure it is scheduled on the timeline.**

### **EXPLORATION DTOS**

#### **SuperLite-17 (SL-17):**

The SL-17 is an excellent analog for exploration EVA suits. The procedures for donning/doffing and using the equipment are straight forward and safe. A SL-17 checklist was developed and strictly followed before and after each dive. One significant downside of using the SL-17 system is managing the umbilical. Umbilical management techniques provide an additional overhead that must be planned for. For all exploration activities we learned that one crewmember needed to be designated solely to umbilical management. The limitations of an umbilical exploration system are exploration lessons learned themselves (see Appendix 4). Both the EV and IV roles provided significant space flight readiness training for the crew. It is especially important to allow the IV crew members to take on as much of the responsibility as possible for the hands-on activities associated with suiting up the EV crew members. The habtech crew members can provide a valuable oversight role for these activities.



### ROV – Scuttle

For the NEEMO 9 mission we operated the Outland “Scuttle” ROV in both the driving and flying modes. This was done both with local control by the crew inside Aquarius and remote control by the ExPOC in Houston. Scuttle was a useful tool to evaluate integrated human/robotic operations related to Lunar Exploration objectives.



The more information the crew has on the operation of the ROV prior to the mission the better. This information should include a description of the ROV capabilities and user control interface, and clearly written procedures for the set up and operation. Prior to the mission the crew should be given the opportunity to perform an end-to-end procedure review with the hardware. For NEEMO 9, the primary issues with the ROV had to do with unclear procedures (e.g., steps for local vs. remote control) and computer setup for remote operations (e.g., IP addresses, software required up and running on both the local and remote computers, com port configuration).

The actual driving/flying of Scuttle was straight forward. There were some subtle handling qualities that had to be managed (e.g., requirement for continuous input of left yaw as soon as you lift off the sea floor, umbilical management, use of full vs. 50% power). We would also suggest some minor modifications to improve Scuttle operations (e.g., rear camera view, extendible gripper).

If we are going to continue to use ROVs for NEEMO missions and evaluate their application to Exploration objectives, it is necessary to develop “flight rules” associated with ROV operation. These flight rules should at a minimum include power restrictions, operator certification requirements, and distance limits from crew and other vehicles.

A graphic “map” of the habitat structure and the local area and structures within the operating range of the ROV would be an extremely useful situational awareness tool –

for both local and remote operations. In the meantime, it is extremely useful to have your habitat technician crew members involved with ROV operations; both inside Aquarius monitoring the video and outside as an ROV monitor/tender. They proved to be our best situational awareness asset.

Refer to Appendix 3, for a summary of ROV procedures, troubleshooting tips, and lessons learned.

### CobraTac Navigation System



The CobraTac system has some great capabilities and exploration applications, however it also has some serious limitations:

- The CobraTac menu buttons were not consistent in responding to button selections.: While taking marks there were at times enough of a delay from the time you pushed the “mark” button to the time it showed up on the screen that you might think the button push hadn’t actually taken, and then get impatient and hit the mark button again. If this occurs you must hit cancel and start over. When using the grid mode it is important to ensure that you observe the expected feedback after any button push. In other words, sometimes when a button was pushed to change modes or to set a new leg/lane no change was observed.

***Recommendation 33: An improved method is required to protect the battery cable from Cobratat once the battery is disconnected.***

***Recommendation 34: A serial cable extender needs to be incorporated to go from the Cobratat download cable to the back of the computer.***

Problems with the download occur when the COM configuration on the laptop does not agree with those selected in the Cobraware. To verify configuration: right click on My Computer and go into hardware – device manager – ports and check the settings for the COM port. It is possible to use any COM port not in use by the computer provided the same COM port is selected in Cobraware. The settings for the COM port in device manager MUST match those in Cobraware – baud rate, parity, stop bits etc. Once the settings are the same, 115200 worked without problems. It is significantly faster – 1 hour versus 6 hours.

**Recommendation 35: For Navigating Menus a definitive answer needs to be found to the following question: If useable data was recorded is it required to go back to the main screen before powering off CobraTac?**

**Recommendation 36: The internal CobraTac software should be upgraded with a direct GO TO capability and real time truth update features. In other words the capability should exist to update the CobraTac's state vector by "marking" on known locations.**

**Recommendation 37: There should be a reminder in the training and procedures about how the screen goes into a blank standby mode ----- therefore, power is still on and you can risk draining the battery if you don't recognize this. The documentation says that the screen will have a light glow to it when it is in this mode, but none of us could tell the difference from when it was off.**

**Recommendation 38: DOWNLOAD PROCEDURES - When putting execute notes in the OSTPV activity details, these notes should clearly reflect the kind of data download they are asking for and the words used should match the words used in the appropriate section of the procedure. Also, there should be clear direction regarding deleting any data.**

We only deleted when it was specifically called out to us. This is the safest way to operate to ensure nothing is lost, but it also requires the topside team keep track of how much is on the CobraTac memory at any given time to prevent the problem we encountered during one of our dives where the recorder filled up and wasn't able to record anymore of the bathymetrical data.

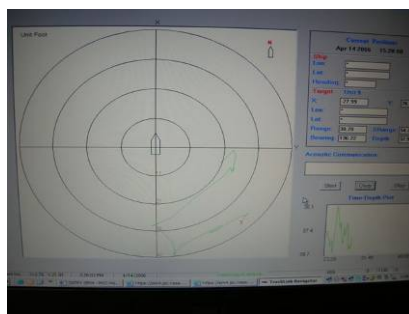
**Recommendation 39: GRID MODE - When pushing "Start" do not begin using CobraTac to navigate until "Start" changes to "Leg". This was the only indication that was observed to indicate that the Grid Mode was active.**

When arriving at the end of a leg, turn 90 degrees and push the "Leg" button. Do not proceed to the next leg until you observe the "beach" indicator in the upper left rotate 90 degrees. If it does not rotate push the "leg" button again until it rotates.

#### Tracklink Diver Tracking System:

The exploration DTOs incorporated using a diver tracking system called Tracklink to follow the position of crew performing EVAs. This system utilized an antenna mounted above the Aquarius habitat to track transponders that were mounted to either divers or the ROV. The tracking hardware interfaced with a software system that displayed range and bearing information for each transponder. The system was quite accurate and significantly enhanced the situational awareness of the IV crew while supporting EVAs and ROV operations.





**Recommendation 40:** Provide an overlay of Aquarius and the adjacent reef. This will enhance IV situational awareness of the location of either the crew or ROV to known points on the reef.

## **EXPLORATION SCIENCE**

### **Lunar Surface EVA DTO**

A DTO to evaluate the work and time efficiency of performing an EVA from Aquarius was performed to obtain data to assist with planning future lunar surface EVAs. Current pre-breathe protocols and EVA Prep activities for ISS spacewalks add a significant lead time decreasing the overall efficiency of spacewalking tasks. The frequency with which astronauts living in lunar habitats will perform surface spacewalks will drive requirements for a time efficient EVA Prep and Post protocol.

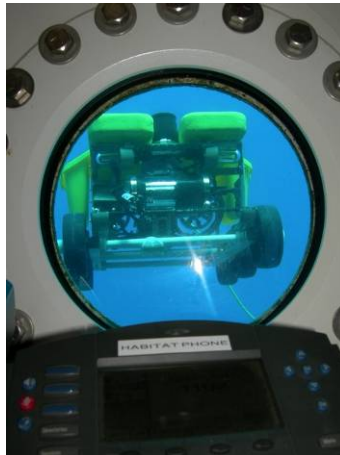
For N9 diving activities, crew completed a work efficiency index (WEI) and time efficiency index (TEI) after each dive. An Excel spreadsheet was used for data collection. There were no issues associated with the data collection system.

An evaluation of the effects of different center of gravity (C of G) configurations was performed during Superlite dives. Crew were given a PLSS mock-up that could be reconfigured to different C of G configurations and asked to perform a number of tasks similar to those that will be performed during lunar surface EVA. The DTO was supported by NBL divers which facilitated changing the C of G configurations between tasks. Overall the DTO went very well although there were some comfort issues with the shoulder straps on the PLSS mock-ups, the amount of weight carried and the effects of different C of G positions.



This type of DTO is a great demonstration of the value of Aquarius as an analog environment for space exploration research. The effect of different C of G configurations was clearly evident and the lessons learned will undoubtedly have a significant impact in preventing some of the falls that occurred during Apollo lunar EVAs. All of the EVA activities also provide excellent training and lessons learned with regard to IV support required. It's very important that the crew participate in these IV activities as well.

#### Vehicle Inspection DTO:



This DTO evaluated the efficiency of using an ROV used in the free flyer mode to perform an inspection of the exterior of the habitat. The IV ROV operators were able to successfully perform an overall and detailed assessment of the habitat without colliding with the structure. The habitat technicians were an invaluable resource in knowing what portion of the habitat was a keep out zone and which areas could be safely approached.

#### Cargo Vehicle Search and Recovery DTO:



This DTO compared the efficiency of ROV vs. human search and retrieval of a simulated spacecraft delivering cargo to a lunar habitat. The ExPOC provided approximate range and bearing information to the crew with directions on how to conduct the search. While lunar missions will likely have the capability to track and navigate to re-supply spacecraft this DTO was valuable in understanding the value of controlling lunar rovers from a habitat.

#### Simulated Lunar Sample Retrieval and Handling DTO:

Simulated lunar specimens were placed on the reef adjacent to Aquarius and this DTO evaluated the efficiency of searching for and retrieving the samples during an EVA or using an ROV operated either IV from the habitat or remotely from the ExPOC. In general the EVA retrieval proved most efficient but further work should be done to evaluate the efficiency of rovers working concurrently with crew performing EVA.



Once retrieved, the samples were sorted with lunar planetary geologists at Johnson Space Center guiding a remotely located robotic operator using the SRI M7 robot to sort the specimens. This type of DTO to assess the role for telescience and telementoring of geologic procedures is of tremendous importance to developing future lunar research protocols.

#### Waterlab DTO:

The Waterlab DTO was similar to that performed on previous NEEMO missions, but with all construction activities taking place during Superlite dives and the incorporation of a lunar construction scenario. This activity simulated the construction of a lunar communication relay station. During the Apollo program there was no requirement for EVA crewmembers to communicate with their landing vehicle/habitat. Crewmembers during Apollo communicated directly to Earth. Due to the planned increase in lunar surface crew size, in the future it may be beneficial for crewmembers to have the capability to communicate to crewmembers remaining in their habitat while conducting surface exploration. The lunar horizon for an EVA crewmember is ~2.4Km. In order to communicate to the habitat while on excursions beyond 2.4km a comm. relay station will need to be constructed. A 20' (6.15m) relay tower would increase the communication range to ~9km.



Construction of the simulated relay station during the waterlab exercise had the following objectives:

1. What is the feasibility of an EVA crewmember operating in a lunar gravity environment to construct a 20' Communications relay structure?
2. What is the feasibility of incorporating robotic collaboration during construction tasks?
3. What lessons can be learned for the development of robotic collaboration with surface construction tasks?
4. Evaluate what roles/assistance can IV crewmembers / MCC provide during surface exploration
5. Assess long duration effects of various CG configurations
6. Assess long duration effects of various CG configurations
7. Assess the utility of the variable CG PLSS rig
8. Does the PLSS rig create any discomfort?
9. Does the PLSS rig cause any restrictions in movement?

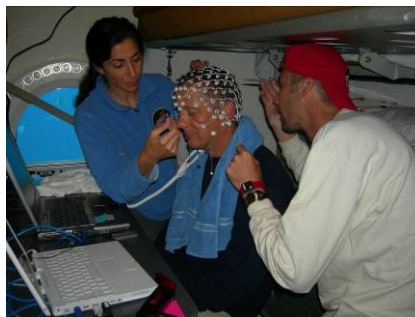
This activity was helpful in providing crew with experience working with a number of tools to build a complex structure while maintaining SA about consumable management, umbilical management and communication with an IV crew member.

## **CMAS SCIENCE**

### Aquarius as a Space Telemedicine Analog:

NEEMO 9 proved to be an excellent space telemedicine analog. CMAS telehealth science schedule was aggressive but successfully completed. Of note, the extreme environment, cramped space and imposed lunar latency were overcome and preliminary data suggests telerobotics and robotic telesurgery could have a role in lunar medical care. As a research platform, NEEMO successfully served as an advanced medical technology accelerator that effectively pushed research personnel and technology. The crew worked as proxy scientists to accomplish research objectives and deliverables in a manner similar to science conducted during spaceflight. Eclectic expertise and support as part of CMAS science improved all aspects of mission. For example, exploration science was symbiotically improved by the networking expertise and resources used to accomplish CMAS telehealth research. International and military collaboration as part of CMAS science added much to the mission including broadened media interest and coverage. CMAS telehealth research helped make NEEMO 9 a mission, not strictly a training exercise.

### CMAS 1 – Impact of Latency on Brain Activity and Task Performance.



In this experiment, NASA crew members performed 3 virtual reality (VR) tasks while having their brain activity recorded by dense array electroencephalogram (EEG). The VR tasks included ball catch, box draw and arc draw under conditions of latency that ranged from 0 – 750 msec. Variable auditory stress was also imposed during task performance that included white noise and simulated helicopter in flight.

A significant amount of the mission timeline was dedicated to this experiment. Concerns regarding electromagnetic interference (EMI) limiting quality of EEG data gathered in the habitat appear unfounded. The crew successfully placed EEG nets on each other and set up a fairly complex EEG monitoring system in part secondary to excellent training, procedures and in-mission support. The auditory stress was considered ineffective as both recordings provided sufficient noise to drown out ambient noise, but offered little additional stress to data collection. EEG electrolyte wetting had to be performed by the experimental set up in the bunkroom. Unfortunately, the G4 notebook port failed after a small spill of electrolyte solution onto the keyboard. This forced timeline rework that allowed an additional day of CMAS5 experiments. The laptop failure also resulted in the first white space that the crew was able to use during the mission. The laptop was subsequently replaced with a new laptop that had been purchased, loaded with software, and potted down to Aquarius. Unfortunately, an unrelated failure of the EEG amplifier precluded further data collection. Despite the technical challenges that resulted from laptop and amplifier failure, significant data was collected and the experiment was successful.

Preliminary data analysis suggests dense array EEG monitoring is possible in Aquarius. This represents the first time dense array EEG data were collected during undersea saturation and under various latency conditions. The crew subjectively noted adaptation to latency. We look forward to further discussing latency adaptation with investigators after data analysis is completed.

***Recommendation 44: Experiments should use standard NEEMO laptops as opposed to the Apple laptop. If it is not possible to use EEG software loaded on standard hardware, recommend back up laptop in the habitat or NURC base ready in case of hardware failure. Also recommend back-up amplifier. General recommendation for use of standard hardware and software is detailed below.***

***Recommendation 45: Consider modifying VR tasks more closely approximate telesurgical tasks.***

#### CMAS 2 – Acquisition and Interpretation of Digital Radiographs in an Extreme Environment

In this experiment, non-medical NASA crew (RG and NS) explored the ability of a non-medical Crew Medical Officer (CMO) to obtain and interpret digital radiographs in an extreme environment. There was significant overhead in modifying (removing x-ray tube) and potting the relatively large and heavy digital x-ray machine down to the habitat. The crew successfully used this equipment and the CMAS Extreme Radiology Manual to simulate acquisition of AP and lateral wrist and ankle images. Digital radiographs that had been previously taken at CMAS were successfully transferred to CMAS and then interpreted by crew. The CMAS Extreme Radiology Manual was excellent.

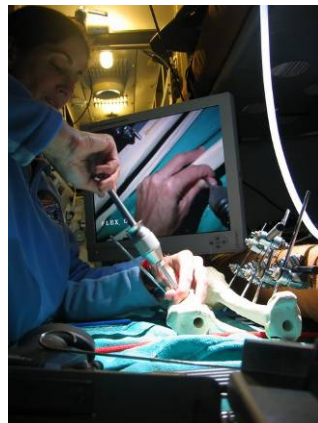




The experiments confirmed that non-medical CMO could obtain digital radiographs quickly and efficiently when supported by an appropriate manual. Non-medical crew successfully recognized abnormal radiologic findings such as small fractures when radiographs were compared with radiographs of the contralateral normal limb. These experiments suggest that an appropriately supported CMO can acquire and interpret digital radiographs as necessary during future space exploration.

***Recommendation 46: Consider reducing the amount of large and heavy equipment that is potted down to Aquarius in support of this type of experiment. The important aspect of this experiment was primarily the evaluation of the radiographs, and this could have been performed successfully without any of the equipment or perhaps with something as simple as cardboard mockups. (However, continue to pot down the foot and arm).***

#### CMAS 3 - Telementored External Fixation of a Tibial Fracture



In these experiments, NASA crew members simulated telementored external fixation of a tibial fracture. A medical and non-medical crew member performed the external fixation with telementoring under real time latency (@ 200 msec). The other medical and non-medical crew members performed the fixation with telementoring under lunar latency (2 sec). The simulated tibia and fibula were adequate despite the lack of overlying soft tissue. The crew was concisely trained prior to the mission in use of the external fixation equipment and appropriate anatomy. The telementoring of Dr. Tony Adile from CMAS was excellent.

Data analysis is underway. Expert telementor and telementee overcame lunar latency to permit successful, efficient fixation of a tibial fracture. Fixator constructs were solid and suggested possible benefit in treatment of open fractures during future space exploration. Additional research clarifying the role of external fixation is necessary. Telementoring could augment medical care provided during future lunar exploration.

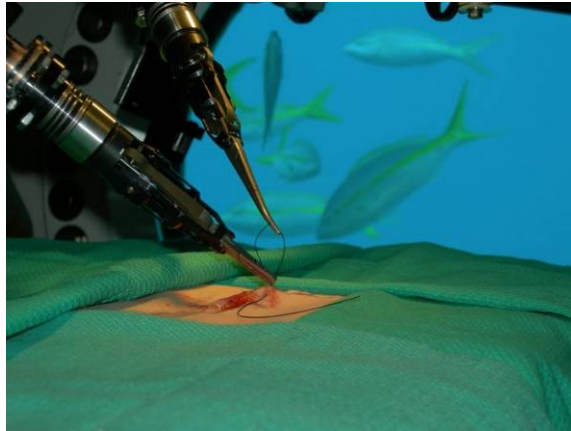
#### CMAS 4 – Telementored Knee Ultrasonography and Simulated Arthroscopy



In these experiments, medical and non-medical crew members imaged the knee of a crew member using ultrasound (US). They then used standard arthroscopic equipment and an inanimate simulator to perform knee arthroscopy. Two crew members were more extensively trained prior the mission in knee US. These crew members used an excellent knee US manual and also were expertly telementoring by Dr Julian Dobranowski under real time latency (@ 200 msec). The other medical and non-medical crew members performed similar tasks with minimal pre-mission training and telementoring under lunar latency (2 sec). All crew members performed knee arthroscopy after basic arthroscopic pre-mission training using an excellent knee arthroscopy manual. Expert telementoring was provided at the previously mentioned latencies. Pre-mission training was appropriate for both groups. Telementoring of Drs Dobranowski and Adile from CMAS was excellent.

Data analysis is underway. Expert telementor and telementee overcame lunar latency to permit successful, efficient imaging of the knee via US. Simulated telementored arthroscopic diagnosis and treatment of knee pathology was also successful. Ultrasound and MIS surgery could be of benefit in the diagnosis and treatment of musculoskeletal injuries during future space exploration. Addition research clarifying the role of musculoskeletal US and MIS surgery is necessary. Telementoring could augment medical care provided during future lunar exploration.

## CMAS 5 – Telepresence Surgery Using a Portable Robotic System



These experiments were a scientific high point of the mission. With successful pre-mission training, the crew successfully assembled and facilitated remote use of the SRI International M7 Telepresence Surgical System. This represents the first time that such a system has been successfully deployed and used in an extreme environment. In addition, this was the first time that a surgeon (Dr Anvari in Hamilton, Ontario) was able to overcome induced latency of over 2 seconds.

During the first day of experiments, significant weather and wave action impaired microwave communication from the LSB to the NURC base. The network provided connectivity that initially permitted limited telesurgical manipulation. The bandwidth of the microwave connection was estimated at 10 Mbps maximum during these initial experiments. However, usable bandwidth was significantly decreased by concurrent mission activities such as PAO videoteleconferences. Latency was at times as high as 4 sec and jitter was up to 1 sec. The bandwidth, latency and jitter forced us to limit concomitant network traffic and decrease robot cycle rate (to limit bandwidth use).

Multiple re-initializations during the rectification of network issues result in a mechanical failure of one of the robotic arms. The failure posed no safety risk but did preclude grasping with the instrument. Crew recognized failure and using the VBrick Internet video image proposed repair to the topside SRI engineer. The crew subsequently fixed the system via reapproximation/cementing of the stripped rod at the point of the robotic arm/end effector interface.

Software and hardware failure in CMAS 1 allowed addition of a second day of CMAS 5 experimentation. Successful suturing and lunar sample analysis occurred on the second day. With the network and mechanical issues resolved, Dr Anvari was able to successfully suture a simulated laceration at lunar latency. He also used the telerobotic system to manipulate simulated lunar rock samples under the direction of JSC lunar geologists.

Successful telesurgery in an extreme environment at lunar latency was very well received by our academic, industrial and military collaborators. The print and broadcast media provided very positive coverage of these telesurgery experiments.



Further evaluation of the role of medical and non-medical telerobotics in space exploration is warranted.

#### CMAS 6 – Haptic Telementoring.

In these experiments, the crew successfully used a haptic telementoring system provided by Handshake VR. Their device uses proprietary hardware and software to ameliorate latency and thereby improve the stability of a distributed haptics system. Using this system, the crew members were able to “feel” simulated virtual tissue as well as the remote guidance of Dr Anvari. These limited experiments suggest that latency can be ameliorated to support haptic telementoring at latencies up to approximately 500 msec. Future telehaptics research is required to further mitigate the effect of latency and discern appropriate medical applications.



#### University of Nebraska In Vivo Robots



In these experiments, the crew evaluated use of prototype small intracavitary surgical robots. The crew compared surgical procedure performance in an inanimate simulator using roboscopic and standard laparoscopic imaging systems. The tasks performed included: rope run, grasp/cut, and appendectomy. The robots performed well. Their mobility subjectively improved the view by allowing the operators to see around objects that limited the view provided by the standard laparoscope. Data analysis is underway. Limited analysis suggests that mobile intracavitary robots could provide better viewing angles that could translate into improved surgical performance. Furthermore, small deployable robots could permit minimally invasive diagnostic and limited therapeutic

capabilities in extreme environments. Further research and development of these systems is underway. This research was well covered by print and broadcast media.

General CMAS telehealth science recommendations:

**Recommendation 47: *Strongly recommend to continue externally funded, collaborative science in future missions.***

**Recommendation 48: *Proxy science training and research of value to crew and should be encouraged in future missions.***

**Recommendation 49: *As much as possible, use standard NEEMO hardware and software to complete science.***

**Recommendation 50: *As funding permits, provide adequate number of NEEMO laptops for concurrent use in exploration and telehealth research.***

**Recommendation 51: *Select crew with IT skills required to support exploration and telehealth science.***

**Recommendation 52: *Select crew with basic medical skills required to support telehealth research specific to mission (vascular anastomosis on N7 and musculoskeletal ultrasonography on N9).***

**Recommendation 53: *Procedure creation and verification are time consuming, iterative and should begin as early as possible.***

## **NSBRI SCIENCE**

Five experiments from the NSBRI were added to the payload to evaluate individual and group performance on the longest NEEMO and Aquarius mission to date. Each of the experiments were selected through a peer review process and were approved by the JSC HRMRB as well as the TATRC, St. Joseph's Hospital and University of Cincinnati IRBs. Baseline data collection occurred pre-mission and data was collected both during and after the mission. Pre-mission experiment hardware training was given at Johnson Space Center. The following is a brief description of the experiments and crew comments where applicable.

### **NSBRI 1 – Linguistic, Physical, and Cognitive Indices of Group Process and Interpersonal Communication in Remote, Isolated Environments.**

Long duration space flight can lead to problems associated with group dynamics. It will be critically important for crews to continue to work together effectively while being confined to small spaces far from Earth for long periods of time. Group dynamics (language, physical cues, and implicit cognitions) could have an impact on constructs such as leadership, information-sharing, dominance, or situational awareness. Group dynamics factors could be useful in predicting team breakdown or task failure.

The majority of the data analysis occurred post-mission using video and voice recordings of team task work (e.g., telemedicine tasks, EVAs, and others if scheduled). Crew time requirements for data collection were minimal. Crew members completed a

brief (approximately five-minute) cognitive reaction time task via computer after the four telemedicine tasks.

#### NSBRI 2 – The Effectiveness of Embedded Cognitive Performance Readiness Measures in a Telemedicine / Telesurgery Spaceflight Analog Environment.

In spaceflight, astronauts will be required to do many different critical tasks, potentially with associated stress. The development of embedded performance tests that can be successfully related to performance readiness metrics could give the astronaut and mission control information on the best time to perform critical events as well as an assessment of the need for countermeasures.



The two cognitive measures used were the MiniCog/Rapid Assessment Battery (MRAB) and the Perceptual Vigilance Test (PVT). Both tests contain tasks that allow investigators to distinguish between the effects of stress and fatigue on performance. The two measures of stress will be cortisol level and computerized optical recognition metrics based on habitat surveillance video.

There were no issues with either the MRAB or PVT hardware and the amount of time allocated in the timeline for each portion of the experiment was appropriate.

NSBRI 3 – Team Cohesion and Productivity, Stress Indicators, Readiness to Perform. Long duration space flight can lead to problems associated with group dynamics. It will be critically important for crews to continue to work together effectively despite being confined to small spaces far from Earth for long periods of time. This study was designed to assess individual astronaut and crew performance readiness, stress levels, and effectiveness as a team. The data collected will help researchers learn how to improve and refine tools for real time monitoring and develop predictive models that can be tested in other analog studies. The eventual goal is to develop a suite of tools that astronauts can use in spaceflight.

Data collection began with mission training and included a session of pre-mission interviews. Follow-up interviews were conducted following the mission.

#### NSBRI 4 – Sleep/Wake Actigraphy and Light Exposure Measures in an Extreme Environment.

The success and effectiveness of human space flight depends on the ability of crewmembers to maintain a high level of cognitive performance and vigilance while operating and monitoring sophisticated instrumentation. However, astronauts commonly experience sleep disruption and may experience circadian phase misalignment during space flight. Relatively little is known of the prevalence or cause of

space flight-induced insomnia in short duration missions, and less is known about the effect of long-duration space flight on sleep and circadian rhythm organization.

Crewmembers used an Actiwatch to monitor sleep-wake activity patterns and light exposure. The Actiwatch was removed prior to diving and put on after returning to the habitat. A brief written evaluation of sleep quality and daytime alertness was recorded daily.

There were no hardware or timeline issues associated with this experiment. There were a couple of situations where the Actiwatchs were inadvertently exposed to water. They were immediately dried and there was no loss of data.

***Recommendation 54: Developing a waterproof Actiwatch would add to the capability to perform circadian physiology experiments in extreme environments.***

NSBRI 5 - Psychophysiological Measures During Confinement in an Underwater Habitat  
Certain phases of long duration space flight may require monitoring psychophysiological measures on individual crewmembers. The means to measure this data cannot interfere with the crew's ability to function effectively. This study obtained human physiological data of crewmembers during normal working hours while wearing an ambulatory monitoring system (AMS). The signal quality, ease of operation, and crew comfort of the AMS was assessed. Two crewmembers wore the AMS during the day on 3 days during the mission.



Overall, the AMS was not unobtrusive. The garment kept the subjects warm in the cool environment of the habitat but this would be a problem if the subjects had to exercise while wearing the garment. It could also be an issue if the temperature of the habitat were higher. Use of a garment to hold the sensors and wires creates the need to either be able to wash the garment or have multiple garments available for long duration missions. A system that can be used with regular crew worn clothing is desirable.

There was no capability to determine if an electrode had fallen off and the data recording had stopped. This required frequent verification that the unit was still recording data which presented a challenge with all of the other demands the crewmembers faced. The design of the EMG electrode connection to the wire harness

needs to be reassessed. The software interface to verify the physiologic signals worked but could benefit from a more user friendly design.

This hardware is not yet ready for spaceflight. With further development and test evaluations on future NEEMO missions we are confident it can become a useful tool for physiologic data monitoring in space.

**Recommendation 55: For all of the NSBRI Behavioral Science experiments the crew is required to provide a significant amount of information and time. It is especially important for the investigators to provide the crew with a timely post-mission report or debrief on the overall findings.**

## **CONCLUSIONS**

NEEMO 9 was the longest and most scientifically ambitious of any NASA undersea mission to the Aquarius habitat. Despite a number of hardware failures and technical challenges the extraordinary teamwork of the crew, the NASA/NURC topside team in Key Largo, the ExPOC, and the science team resulted in mission success. The addition of exploration enabling DTOs that were added to assess different aspects of planetary spacewalks enhanced the mission objectives. These test objectives have already provided data that has changed the approach to lunar spacewalks.

NEEMO missions are a tremendous opportunity for NASA to conduct exploration enabling research and provide astronauts with an opportunity to enhance their skills. The diving skills, both SCUBA and Superlite, are directly transferable to EVA and it was evident that the 3 dimensional situational awareness and importance of camera views for ROV operations is relevant to spaceflight PDRS operations. Perhaps the greatest benefit to the astronaut crew members is the experience gained from completing a real and scientifically significant mission. There are number of more subtle benefits from this experience relevant to spaceflight that include: following a mission timeline, using ISS timeline and procedure tools (OSTPV, IPV, JEDI), photo-TV skills, procedure development and verification skills, IFM skills, as well as developing computer skills with a need to troubleshoot hardware, software and network problems.

As NASA enters the era of space exploration, a terrestrial analog that can be used as a research and technology development platform is critical. Undoubtedly a wide range of analogs will be used in preparing for future lunar missions and the legacy of the NEEMO program will be a key element in enabling the footsteps back to the Moon and on to Mars. NASA should establish a long term agreement with NOAA to continue the NEEMO program in five year increments and provide sufficient annual funding to support future NEEMO missions. It is clearly evident from the many academic and government partners that have been involved in NEEMO missions that Aquarius is a national asset of tremendous importance to the scientific community.

## **APPENDICES**

### **Appendix 1: Dive Chronology**

<b>DATE/MISSION DAY</b>	<b>Name</b>	<b>Mode</b>	<b>Location</b>	<b>Depart</b>	<b>Return</b>	<b>Depth</b>	<b>Time</b>
<b>4/3/2006 MD1</b>	Williams	S	Kamper < 95'	10:38	11:36	88	58
	Stott	S	Kamper < 95'	10:38	11:36	89	58
	Garan	S	Kamper < 95'	10:38	11:36	90	58
	Broderick	S	Kamper < 95'	10:38	11:36	90	58
<b>4/3/2006 MD1</b>	Williams	S	NE < 95'	16:49	17:45	62	56
	Stott	S	NE < 95'	16:49	17:45	62	56
	Garan	S	NE < 95'	16:49	17:45	62	56
	Broderick	S	NE < 95'	16:49	17:45	60	56
<b>4/4/2006 MD 2</b>	Hein	H	Habitat	9:25	12:33	65	188
<b>4/5/2006 MD 3</b>	Hein	H	Habitat	7:46	12:24	65	278
	Hein	H	Habitat	n/a	n/a	Storage	12
	Stott	SL17	Habitat	16:10	16:28	65	18
	Broderick	SL17	Habitat	15:56	15:59	70	3
	Hein	H	Habitat	n/a	n/a	Storage	5
<b>4/6/2006 MD 4</b>	Williams	SL17	Habitat < 95'	8:35	9:59	65	84
	Garan	SL17	Habitat < 95'	8:45	9:26	65	41
	Stott	SL17	Habitat < 95'	15:38	17:06	65	88
	Broderick	SL17	Habitat < 95'	15:27	16:41	65	74
	Hein	H	Habitat < 95'	11:37	14:45	65	188
<b>4/7/2006 MD 5</b>	Williams	S	Kamper < 95'	8:52	10:30	91	98
	Garan	S	Kamper < 95'	8:52	10:30	89	98
	Hein	SL17	Habitat < 75'	11:08	11:24	65	15
	Hein	H	Habitat < 75'	12:19	15:57	65	218
<b>4/8/2006 MD 6</b>	Williams	SL17	Habitat < 95'	16:04	17:46	65	102
	Garan	SL17	Habitat < 95'	16:10	17:58	65	106
	Hein	H	Habitat < 70'	9:43	11:25	65	102
	Hein	H	Habitat < 70'	13:48	15:05	65	77

DATE/MISSION DAY	Name	Mode	Location	Depart	Return	Depth	Time
<b>4/9/2006 MD7</b>	Williams	S	Kamper < 95'	6:53	9:12	90	139
	Garan	S	Kamper < 95'	6:53	9:12	90	139
	Stott	S	Kamper < 95'	6:53	9:12	90	139
	Broderick	S	Kamper < 95'	6:53	9:12	90	139
	Hein	H	Habitat < 70'	13:30	16:34	65	184
<b>4/10/2006 MD8</b>	Stott	SL17	Habitat < 95'	9:10	9:42	65	32
	Broderick	SL17	Habitat < 95'	8:22	8:37	65	15
	Williams	SL17	Habitat < 95'	14:44	16:52	65	128
	Garan	SL17	Habitat < 95'	14:39	16:48	65	129
	Hein	H	Habitat < 70'	18:01	18:37	65	36
<b>4/11/2006 MD 9</b>	Williams	S	Ridge to NASA Loop	8:19	10:47	90	148
	Stott	S	To S4	8:19	10:47	90	148
	Broderick	S	Fill at Kamper	8:19	10:47	88	148
	Garan	S	As Above	8:19	10:47	90	148
	Williams	S	5 <sup>th</sup> Leg < 95'	14:14	15:34	78	80
	Garan	S	5 <sup>th</sup> Leg < 95'	14:14	15:34	78	80
	Hein	H	Habitat < 70'	14:40	17:08	65	148
<b>4/12/2006 MD 10</b>	Williams	S	Kamper to 5 <sup>th</sup> leg < 95'	8:08	10:33	90	145
	Garan	S	Kamper to 5 <sup>th</sup> leg < 95'	8:08	10:33	90	145
	Stott	S	5 <sup>th</sup> Leg S4 NASA Loop	15:18	17:19	82	121
	Broderick	S	To Ridge < 95'	15:18	17:19	82	121
	Hein	H	Habitat < 70'	13:40	16:54	65	194
	Buckley	SL17	Habitat < 70'	18:04	18:55	65	51
<b>4/13/2006 MD 11</b>	Williams	SL17	Habitat < 95'	8:29	11:39	65	182
	Garan	SL17	Habitat < 95'	8:43	11:27	65	164
	Hein	H	Habitat < 70'	10:01	13:30	65	209
	Buckley	H	Habitat < 70'	15:30	16:50	70	80
	Williams	H	Habitat < 70'	18:42	19:13	65	31



DATE/MISSION DAY	Name	Mode	Location	Depart	Return	Depth	Time
<b>4/14/2006 MD 12</b>	Williams	SL17	Habitat < 95'	8:39	11:34	70	175
	Stott	SL17	Habitat < 95'	8:52	11:29	70	157
	Broderick	SL17	Habitat < 95'	14:36	16:47	65	131
	Garan	SL17	Habitat < 95'	14:45	16:38	65	113
	Buckley	H	Habitat < 70'	10:12	11:38	70	88
	Hein	H	Habitat < 70'	16:20	18:52	65	152
<b>4/15/2006 MD 13</b>	Buckley	H	Habitat < 70'	9:48	11:17	65	89
	Stott	S	Habitat < 70'	11:51	14:18	68	147
	Broderick	S	Habitat < 70'	11:51	14:18	62	147
	Williams	S	5 <sup>th</sup> Leg < 95'	20:04	21:45	80	101
	Garan	S	5 <sup>th</sup> Leg < 95'	20:04	21:45	76	101
	Stott	S	5 <sup>th</sup> Leg < 95'	20:04	21:45	73	101
	Broderick	S	5 <sup>th</sup> Leg < 95'	20:04	21:45	78	101
	Hein	H	Habitat < 70'	16:43	18:46	70	123
<b>4/16/2006 MD 14</b>	Buckley	H	Habitat < 70'	9:27	10:15	70	48
	Williams	H	Habitat < 70'	16:00	16:17	63	17
	Broderick	H	Habitat < 70'	16:43	18:30	65	107
<b>4/17/2006 MD 15</b>	Stott	SL17	Habitat < 95'	9:16	10:41	70	85
	Broderick	SL17	Habitat < 95'	9:07	10:46	70	99
	Williams	SL17	Habitat < 95'	14:22	17:00	65	158
	Garan	SL17	Habitat < 95'	14:29	16:55	65	146
	Hein	H	Habitat < 70'	10:08	14:50	70	282
	Buckley	H	Habitat < 95'	20:02	21:03	70	61
<b>4/18/2006 MD 16</b>	Williams	SL17	Habitat < 95'	8:37	10:24	65	107
	Garan	SL17	Habitat < 95'	8:47	10:18	65	91
	Williams	S	Habitat < 95'	13:09	14:45	60	96
	Garan	S	Habitat < 95'	13:09	14:45	60	96
	Stott	S	TBA < 95'	13:09	15:03	70	114
	Broderick	S	TBA < 95'	13:09	15:03	70	114
	Hein	H	Habitat < 70'	9:32	10:27	65	55
	Garan	H	Habitat < 70'	19:33	19:58	65	25

DATE/MISSION DAY	Name	Mode	Location	Depart	Return	Depth	Time
<b>4/19/2006 MD 17</b>	Williams	S	Between Kamper	8:18	9:47	80	89
	Garan	S	And 5 <sup>th</sup> Leg < 95'	8:18	9:47	80	89
	Stott	S	As Above	8:18	9:47	80	89
	Broderick	S	As Above	8:18	9:47	80	89
	Hein	H	Habitat < 70'	8:04	8:50	70	46

## Appendix 2: EVA Communications Protocol

As in the case of EVA from the Space Shuttle or ISS, effective communication is critical for success. Communication with the two crew performing EVA from the Aquarius habitat is possible using both SCUBA and Superlite equipment. The spaceflight model of an IV and two EV crew members is appropriate. Communication between the ExPOC and the Aquarius EV crew should be done in a manner similar to spaceflight. Optimum communication with EV crew is a learned skill that requires practice. It is important for the IV crew, or the ExPOC, to maintain a high level of SA on the EV crew activities to appropriately time calls to the EV crew avoiding transmission when EV crew are busy or unable to hear the call. The following suggestions are offered based upon N9 crew experience.

1. Preface all calls to EV crew with EV1/EV2 identifier.
2. Due to interference with communications while breathing call crew identifiers three times to get EV crew attention. EV crew should do the same when calling the habitat or ExPOC.  
“EV1, EV1, EV1, IV.....”
3. All communications should use standard phrases and terminology – WILCO, COPY...
4. Abbreviations should be standardized and agreed upon – RTB (return to base – meaning return to habitat).
5. The standard NURC diver recall policy of returning to the habitat if the EV crew do not hear the diver recall within five minutes of leaving the habitat should apply to dives without communications capability. For dives with communications capability the diver recall protocol could be changed as follows: A diver recall is sounded within 5 minutes of leaving the habitat. The divers verbally confirm with the habitat crew that they have heard the signal. If the divers do not hear the signal within 5 minutes of leaving the habitat they will call the habitat and request the signal be repeated. If the divers are unable to contact the habitat to verify the recall signal is heard they are to return to the habitat. Dives at the limits of the excursion lines should include verification that the recall can be heard. This can be done using through water communications to the habitat or hard-line communication from the way station. If the recall is not heard dive operations must be re-located to an area where the recall can be heard.
6. Communication protocols for EV crew to guide an ROV operator may include commands based upon different reference frames. Standard voice commands would be based upon a rover FOR (i.e., Forward, backward, yaw left etc. would be interpreted as Rover forward). As in the case of space robotics operations, stop motion is the nominal command to stop moving the ROV while the phrase “all stop” should denote an urgent need to stop motion and may be associated with powering down the ROV. Very clear communication to power off the ROV is required before EV crew attempt to un-foul a stuck thruster.

Communications protocols, and dive hand signals can be briefed as required in the pre-dive brief.

### Appendix 3: ROV Lessons Learned

#### Outland ROV:

The following is a summary of the procedures that I recall we used for the ROV operations with both local and EXPOC control. For safety reasons it is very important to clearly co-ordinate powering up the ROV and performing thruster checks with the wet porch attendant. A prebrief should be done to review all ROV ops with attendant and operator as well as divers in water. Flight rules regarding ROV ops need to be written and diver hand signals, voice commands to the ROV operator standardized.

#### ROV Local Control: (Do Not Untether ROV until called out in procedure)

1. Connect umbilical to ROV and to ROV control box. Note: keep control box unpowered while making connections.
2. Connect keyboard to ROV control box.
3. Connect ROV control box video out to handheld camcorder to record video signal. We used the JVC without difficulty – the procedures for hooking up the JVC worked fine.
4. Connect ROV hand controller to ROV control box.
5. Verify all connections.
6. Power on control box. Verify video image on monitor in Outland control box. Verify video image in JVC camera – select record.
7. Use hand controller to verify ROV camera up/ down commands function.
8. Use hand controller to verify ROV lights and manipulator function
9. Verify thruster power at 50% - do thruster checks at 50%
10. Have attendant on wet porch verify thruster function; ROV operator calls out to wet porch attendant: Thruster up, Thruster Down, Left lateral, Right lateral, Forward, Backward, Left Yaw and Right Raw. We typically untied the ROV before the thruster checks but the attendant held the umbilical around 4 feet away from the stern of the ROV to prevent it from leaving the wet porch inadvertently.
11. Once thrust checks successfully completed get “GO” from wet porch attendant to fly off the wet porch.
12. Fly ROV off wet porch and proceed away from habitat for ROV ops.

#### ROV Retrieval Local Control:

1. Fly ROV onto wet porch or stop all thruster inputs and have ROV pulled back by umbilical.
2. Once ROV on wet porch with attendant holding the umbilical power down the ROV control box.
3. Disconnect umbilical from control box and ROV.
4. Stow ROV.

#### Stowage Issues:

We should determine the best way to stow the ROV and the ROV umbilical during a sat mission. We stowed both on the wet porch grate underwater which resulted in the need to clean the umbilical contacts around 2/3 of the way through the mission. Stowing the ROV umbilical in the wet porch would be an issue with 2 Super-lite umbilicals in the same area. Our wet porch was pretty crowded during these ops. We need to think about

the number of crew needed to tend umbilicals on the wet porch for joint ROV Super-lite ops.

#### Prebrief for EXPOC Control:

The same comments listed above for the prebrief need to be followed for EXPOC control of ROV. There needs to be an IV ROV operator during EXPOC control of ROV to be available to take over control if the link with the EXPOC fails during ops. This may not be as critical for using the ROV in the “driving” mode but would be very important for ROV ops in the “flying” mode. Flight rules and hand signals need to be developed for EXPOC control of ROV and a “certification” process should be put in place for EXPOC ROV operators. If there is a diver in the water appropriate safety protocols need to be prebriefed and followed.

#### ROV EXPOC Control: (Do Not Untether ROV until called out in procedure)

- 1) Connect umbilical to ROV and to ROV control box. Note: keep control box unpowered while making connections.
- 2) Connect keyboard to ROV control box.
- 3) Connect ROV control box video out to USB Video Converter and handheld camcorder to record video signal. We used the JVC without difficulty – the procedures for hooking up the JVC worked fine.
- 4) Connect USB video device to computer USB port.
- 5) Connect RS232 cable from ROV control Box to computer.
- 6) Go to appropriate folder on computer and run Outland batch file. (I would have ONLY the appropriate batch file in the folder – our folder also had a client batch file and running that inadvertently prevents EXPOC control).
- 7) Verify ROV hand controller is disconnected from control box. Remote control will not work if this is in place.
- 8) Verify all connections.
- 9) Power on control box. Verify video image on monitor in Outland control box. Verify video image in JVC camera – select record.
- 10) Call EXPOC ROV operator to verify they have a video image and data.
- 11) Have EXPOC ROV operator verify ROV camera up/ down commands function.
- 12) Have EXPOC ROV operator verify ROV lights and manipulator function
- 13) Verify thruster power at 50% - do thruster checks at 50%
- 14) Have attendant on wet porch verify thruster function; IV ROV operator gives go to EXPOC ROV operator for each command and calls each command out to wet porch attendant: Thruster up, Thruster Down, Left lateral, Right lateral, Forward, Backward, Left Yaw and Right Raw. We typically untied the ROV before the thruster checks but the attendant held the umbilical around 4 feet away from the stern of the ROV to prevent it from leaving the wet porch inadvertently.
- 15) Once thrust checks successfully completed IV ROV operator gets “GO” from wet porch attendant to fly off the wet porch.
- 16) Either IV ROV operator, or EXPOC ROV operator flies ROV off wet porch and proceed away from habitat for ROV ops. ROV certification may be broken down into driving mode and flying modes. The IV crew must be able to do both. It is possible to certify EXPOC operator for “drive only” mode but it may be more desirable to have them certified for both.
- 17) Continue ROV ops.

#### ROV Retrieval Local Control:

5. Fly ROV onto wet porch or stop all thruster inputs and have ROV pulled back by umbilical. Determine ahead of time if this will be done by EXPOC or IV.
6. Once ROV on wet porch with attendant holding the umbilical power down the ROV control box.
7. Disconnect umbilical from control box and ROV.
8. Stow ROV.

#### Aquarius Troubleshooting for Remote Connection:

1. Verify appropriate IP address for client is set on EXPOC computer
2. Verify that appropriate IP address for EXPOC computer is in the Outland batch file and the Hauptaga video settings.
3. Verify that the hardware device manager settings for COM port 1 are appropriate and not set for some other COM port. Adjust settings as required.
4. Verify no other software (Activesynch) is trying to use the COM port.
5. Verify that only the Outland Batch File is running on the Aquarius computer.

#### Aquarius Troubleshooting for Remote Control:

1. Verify the hand controller is disconnected from the ROV control box.
2. Verify control of the camera and manipulator first. If the EXPOC can control them they are in contact with the ROV and if there is a thruster problem it could either be on the Aquarius side with the umbilical or at the EXPOC side with the hand controller.

#### “Red” High Voltage Light Fails to Illuminate:

In this situation there will be a video signal from the camera on the ROV but hand controller inputs fail to activate the thrusters. The signature is the red annunciator light failing to illuminate. Normally this light is “on” during ROV ops. The procedure has you power cycle the ROV control box. We did this 3 times without success. We then disconnected both the 3 pin and 8 pin connector for the umbilicals and got the red light when we powered up the box itself. We then connected the 3 pin connector and achieved the same result. We suspected the 8 pin connector and connected the 8 pin connector and powered the box on which resulted in the red light failing off. We felt that indicated a dirty (possibly faulty) connector for the 8 pin cable. Cleaning the pins (3 pin and 8 pin) at both ends of the umbilical solved the problem.

## Appendix 4 : Exploration Lessons Learned

### Surface Exploration Lessons Learned Database

There are many analog missions that exist and collectively a great deal of money is spent on these missions but there has not been an effective way to record, consolidate, and disseminate the lessons that we have learned from these missions. Because of this we have designed the Surface Exploration Data Base with the goals of collecting the lessons learned from all the analog missions and Apollo missions and putting these lessons in a format that is manageable and usable for the developers of our exploration architecture. The inputs into this database are in a standardized format and include operationally relevant information. This is a CB controlled and maintained database. We are working to allow access to input to the database from outside the NASA firewall. Any data inputted is initially recorded in a holding database where it is reviewed for relevance and standardized before inclusion into the published database.

The following NEEMO 9 Exploration lessons have been inputted into the Exploration Database:

<b>Mission #:</b>	NEEMO 9
<b>Exploration Topic(s):</b>	General EVA Considerations Lunar Space Suit Design
<b>Exploration Question(s):</b>	Are umbilical EVA's effective for surface exploration? What are considerations for lunar surface EVA suit design?
<b>Overview:</b>	EVA's using an umbilical in lieu of a PLSS worked well as long as the EVA remained relatively close to the habitat....
<b>Lesson Learned:</b>	EVA's using an umbilical from the habitat in lieu of a PLSS worked well as long as the EVA remained relatively close to the habitat. (less than 50 yards). At greater range umbilical management became a big issue and the utility of using an umbilical decreased significantly. Short range EVA's (for habitat maintenance/repairs or tending nearby experiments for instance) are valid uses of an umbilical based EVA. The same lesson applies to umbilical based ROV operations.
<b>Recommendation:</b>	1. Develop workable umbilical management protocol if ROV or EVA will be conducted using an umbilical. 2. Strong consideration should be given to the limitations of operations with an excessively long umbilical.
<b>Hyperlinks:</b>	

<b>Name(s):</b>	Garan, Ron
<b>Mission Type:</b>	NEEMO

<b>Name(s):</b>	Garan, Ron
<b>Mission Type:</b>	NEEMO
<b>Mission #:</b>	NEEMO 9
<b>Exploration Topic(s):</b>	General EVA Considerations Surface Navigation
<b>Exploration Question(s):</b>	What are considerations for lunar surface EVA timeline development? What factors can improve lunar surface navigation capability?
<b>Overview:</b>	On surface EVA's it is desirable to traverse to the farthest planned point first and then work back towards the habitat.....
<b>Lesson Learned:</b>	On surface EVA's it is desirable to traverse to the farthest planned point first and then work back towards the habitat. This allows for required consumable reserve to decrease as the EVA progresses and crewmembers draw closer to the habitat
<b>Recommendation:</b>	Consideration should be given by future lunar surface EVA timeline planners to traverse to the farthest planned point first and then explore/travel back toward the habitat.
<b>Hyperlinks:</b>	

<b>Name(s):</b>	Garan, Ron
<b>Mission Type:</b>	NEEMO
<b>Mission #:</b>	NEEMO 9
<b>Exploration Topic(s):</b>	General EVA Considerations
<b>Exploration Question(s):</b>	How important is real-time electronic monitoring of EVA crewmembers on the lunar surface? What factors can improve lunar surface navigation capability?
<b>Overview:</b>	The ability to view real time electronic tracking of EVA crewmembers provided substantial benefits.....
<b>Lesson Learned:</b>	During NEEMO 9 we deployed the LinkQuest diver tracking system. We found that the ability to view real time electronic tracking of EVA crewmembers provided substantial benefits. If objects of interest are located on the lunar surface that are determined best to leave in-situ (to avoid sample contamination for example), an accurate bearing and range or grid coordinate of that sample will ensure that it can be located when desired. Real time electronic tracking also allowed us to confirm that a specified grid search pattern was accomplished as planned. Using the CobraTac navigation system in the grid search mode EVA



crewmembers conducted a detailed search of our simulated lunar landing area. The tracking system allowed us to confirm that the navigation system was covering the planned search ground track. At one point during the mission a tracking transponder was lost from an ROV. Because the transponder was still operating, finding it consisted of sending an EVA crewmember out with a transponder and providing bearing and range instructions to bring the two tracks together. The ability to track equipment or areas of interest beyond visual range on the lunar surface should be considered for future lunar missions

**Recommendation:**

Further evaluation should be conducted concerning the development and fielding of a real-time electronic tracking system for lunar surface EVA crewmembers.

**Hyperlinks:**

**Name(s):**

Garan, Ron

**Mission Type:**

NEEMO

**Mission #:**

NEEMO 9

**Exploration Topic(s):**

General EVA Considerations  
Operating in a 1/6g Environment  
Lunar Space Suit Design

**Exploration Question(s):**

What are considerations for lunar surface EVA suit design?

**Overview:**

In both the 1/6g & 3/8g gravity fields the farther aft and the higher the CG moved the more objectionable the CG location of the EVA suit became...

**Lesson Learned:**

During NEEMO 9 a variable CG PLSS mockup was worn during various surface EVA tasks (timed walk, timed run, shoveling, fall and recover, kneel and recover, ladder climb, and general construction tasks). These tasks were evaluated using a Cooper-Harper scale under varying CG conditions in both a lunar and Martian simulated gravity field. In both the 1/6g and 3/8g gravity fields the farther aft of center and the farther above center the CG moved the more objectionable the CG location became. The closer the CG was to the normal CG of the human body the easier the tasks became.

**Recommendation:**

Continue to evaluate the effect of CG location on human performance to determine an allowable CG envelope. Design future lunar surface EVA suits to remain within an acceptable CG envelope.

**Hyperlinks:**

Appendix 5: Summary of Still Photography Debrief Questions  
NEEMO 9 Photo Debrief Questions and Answers 4/28/2006

Debrief with Nicole Stott

Did you do all the camera work or did you farm out some of it?

Nicole did all the camera ops work except for putting the video camera in the dive housing and cataloging what was on each of the video tapes. Ron did those two things.

Did the timeline allow enough time to do Photo Ops management? If not, what should be changed?

The Photo management timeslot was not used for that it. That time period was used for other ongoing activities. Photo mgmt was done as part of her pre-sleep activities. During that time she downloaded all the pictures from the cameras, transferred them to Thin Client and picked out the best pictures for the day. She also set up the cameras for the next day and recharged the batteries. It was easy to do and didn't take up much time and was kind of relaxing for her to do at the end of the day. If she had to do any editing other than resizing pictures it would have been an issue.

Any issues with how the camera equipment was potted down (Other than the housing you couldn't open and had to send back up). Could you find everything?

No issues. They were able to quickly locate the equipment.

How did you do photos ops? Sorting and labeling of pictures?

What worked best for her was to insert the memory card in the memory reader. Open that in one window. In a separate window she opened the "My Pictures" folder. In "My pictures, she created a folder for that Mission Day and inside that folder she created unique folders for the different mission events. She then dragged pictures from the memory card to the appropriate folder. For the best pictures of the day, she wrote a description for the file name.

Did you use one computer for photo ops? If so, which one.

Nedland was used

Did you have any issues with the memory card reader?

No issues with the memory card reader. She did have issues that sometimes the computer wouldn't recognize the memory card reader and she would have to reboot the computer to get it to recognize the reader.

Did you save photos in "My Pictures"

Yes. Also kept copies of all the pictures on the memory sticks. She did not use Picassa. Luckily between them, they had enough memory sticks to backup all the pictures. She did not want to delete any pictures off the memory sticks even though she knew Topside had them and they were backing them up. It was cheap insurance for her.

Did you use the photo procedure? Was any if it useful?

They reviewed the procedures for the first few dives but after that they did it from memory because it became second nature.

Did you empty the camera storage cards after each day when you dumped the pictures?

After the pictures were downloaded from each card, the cards were cleared. So the only pictures on the card were the ones taken that day.

Where did you locate the battery chargers in Aquarius? Anything you would do different?

The chargers were located in front of the sink near the wet porch. It worked but they weren't really comfortable keeping them by the sink that they were using. It would have been very helpful if they had a shelf to put the chargers on because that would have given them more space. Chargers were an issue, they just had too many of them. In addition to the ones we sent down, Dave had one for his camera and then you have different ones for the CMAS cameras. The wall wart plugs were also a problem because they took up lots of space on the power strips. Need a better way to handle them.

Did you have enough rechargeable batteries?

Yes, what was sent down was sufficient

Any suggestions or advice for use of Thin Client to download pictures?

Worked great. Sometimes it took maybe 8 minutes to upload the pictures off the memory stick, but you didn't have to stand there and watch it so it wasn't a problem. She put the pictures into a designated folder and she noticed that each day the folder was cleared. This was her clue that the pictures were taken by us or ExPOC.

Did you download pictures at night or in the morning?

Downloaded them each night during pre-sleep.

Could you access the photos on the ExPOC server?

Yes, but it wasn't useful for viewing because it took too long to open even a single folder. They tried once and had to resort to just blindly selecting every fifth picture because even the thumbnails were taking a long time to load. The crew wanted to view the pictures the Topside team was taking. She suggested that if it was easy for the Topside team to transfer the photos to the Thin Client they could view them that way.

Did you remove and clean the camera o-rings daily? If not, what did you do?

Cleaned the o-rings by removing them every three or four days. Checked them every day to look for debris or sand on them. Rubbed her finger on the o-rings to feel for grit and to see if it still had a film of grease on it. O-rings were easy to remove.

Were the lens cleaning cloths adequate? Did you use them?

They were great and used a lot. Some are still left but not enough for another mission. They helped a lot to get the salt water finger prints off the lens.

Did you check the cameras for leaks as soon as got in the water?

Yes. We checked them on each dive. Didn't have any problems

Did any leak?

No

Did you check the cameras for leaks post dive?

Yes

Did you have any issues or lessons learned with the camera housings?

No problem with the camera housings. Used them several times indoors just for the wide angle lens. The camera housing for the canon camera was harder than she expected to open because of the way the latch works.

Did you set up the dive cameras for the next day the night before or the morning of?

She always prepared the cameras the night before. If she wasn't using the dive video camera for a day or two, she left the batteries in the charger until the night before the dive.

You mentioned using a video tape case for a flash diffuser? How did that work?

It worked great to reduce the brightness of the flash. The camera flash is too bright in close quarters. Rather than tape it on the camera, they just held it in front of the flash when then needed it.

Did the ROV-Handycam procedure work as written?

The worked great. They did have some issues with the ROV procedure the way it is written. Some of the steps are for ExPOC and others require a more detailed description to implement correctly.

Did your batteries ever run out during a dive or in Aquarius?

No

Did you have any problems using the canon digital camera in Aquarius? (You mentioned having cameras for use in Aquarius that made it easier to quickly change shot settings. Dave's camera had a setting to compensate for backlighting which was very useful for shots with the window in the view)

The cameras worked fine except as noted.

What photo training would you like to see added or changes? (We discussed yesterday some training on how to take good photos using basic equipment)

Being able to take the camera home was a plus in learning how to use it. It would also be helpful to get the video cameras in a pool to practice some shots, even at night. They were learning video photography on the fly. How does the strobe help or hurt the pictures, what's the range ,etc..

Did you use the video camera tripods?

Used them all, even for still camera photos.

Did you use the Panasonic video camera in Aquarius?

Used it once for a CMAS experiment and used it for filming the ROV video. Did not use it for crew video in Aquarius. For internal video they used the Sony camera. They liked it much better. The Sony was far superior in use and quality over the JVC video cameras they had for CMAS.

Did you use the microphone with the video camera?

No - forget they had it until the end of the mission

Did you have any problems taking photos in the water?

No. They used the wrist strap on the still dive camera. Easy to hold by the strobe arm. Once the fiber optic cable came off and they noticed it floating by the camera. From then on they taped it to the arm. The big problem with the cameras was where to set them down while diving. They didn't carry the lens covers with them and they were concerned about the sand getting into the seals or scratching the lens.

Did you remember to not swim above the windows with the cameras?

Always but not directly. They set a dive excursion limit of 40 feet and this below the windows so it was never an issue.

## Appendix 6: Video Shot List

### VIDEO SHOT LIST

AS OF 2 APR 06

#### **Note Record Tape number and estimated time on tape for each shot**

Category	Notes	Dave	Ron	Nicole	Tim	Jim	Ross
<b><u>General:</u></b> Document all payload & science activities							
Hab Tour							
Shot of crew using OSTP							
<b><u>Splash Down:</u></b>							
Shot topside keep camera running face down into the water and all the way down to the habitat and up through the wet porch	(for post mission video)						
Get everyone's initial impression during pre-sleep							
Equipment Unstow	Get a shot before its unstowed						
Hab Brief							
<b><u>Payload Highlights:</u></b>							
Operation of Surgical Robot							
Get a shot testing wetsuits for bacteria							

Shot potting up samples							
Each crewmember with EEG net							
<b><u>Dawn Dive:</u></b>							
Document changes in marine life and color as the sun rises	(Hopefully with a time elapsed shot on West side of habitat looking East with an angle looking slightly up)						
<b><u>Exploration:</u></b>							
Tell the lunar sample story	ROV sample pick up to SRI robot manipulation						
Donning variable CG PLSS							
Adjusting variable CG PLSS							
Try and tell the story of the cargo ship search (mini documentary)							
Before/After every science activity ask crew to describe exploration scenario, objective and lessons learned							
Shot entering a LL into the LL DB							



**Water Lab:**

All interaction with ROV's

Document construction tasks while highlighting variable CG PLSS

**ExPoc:**

Get a shot in the ExPoc of the display showing our helmet-cam view

Film any VIP visits to ExPoc

Get a shot of ExPoc personnel operating ROVs

Try to include spaceflight like comm. in audio track (get good quality audio)

**SplashUp:**

Mission Impressions from each crewmember

(during decompression)

Decompression (w/ O2 masks on)

record the sound and fogging that we get with the bounce dive prior to splash-up

Blow down							
Hab Exit							
Arrival to boat	Film from the boat						
<b><u>Others:</u></b>							
Crew meal							
Exercise							
Any IFM conducted by HabTechs							
Hooka							

## Appendix 7: Video Shot Log

### **NEEMO 9 VIDEO LOG**

<b>Tape #</b>	<b>MD</b>	<b>Date</b>	<b>Contents</b>
001	2	4 Apr 06	St Joseph Ed Outreach (Ron on EEG)
002	2	4 Apr 06	CMAS1 Facial expressions (Tim, Nicole, Ron, Dave) Dave NSBRI1 (Saliva)
003	1 & 2	3-4 Apr 06	Splashdown potting on wet porch (0-:44), Unstow (:44-2:22), Potters outside main lock, 1 <sup>st</sup> Dive from Aquarius (2:22-21:08), OSTPV narration w/ Ron in AMS, Tim explaining OSTPV (21:08-?), Nicole with EEG while Dave gives teleinterview, More OSTPV narration, Dave & Ron pipetting Nicole (w/ fish in background), Nicole w/ CMAS1
004	2	4 Apr 06	CMAS1 Surveillance (Dave & Tim)
005	2	4 Apr 06	CMAS1 Surveillance (Ron)
006	3	5 Apr 06	JSC Education Outreach (AM)
007	3	5 Apr 06	Aquarius-ISS Comm pass
008	3	5 Apr 06	PAO Event (live interview w/ US & Canada media
009	3	5 Apr 06	ROV orientation & some OSTPV ops
010	4	6 Apr 06	Education Outreach (Mt Carmel attempted participation)
011	4	6 Apr 06	Dave & Ron on SL-17 (Ron's 1 <sup>st</sup> SL-17 dive)
012	4	6 Apr 06	ExPoc control of ROV
013	4	6 Apr 06	CMAS3 Stryker view (Tim & Ron)
014	3	5 Apr 06	UNL Vivo (Surveillance)
015	3	5 Apr 06	Scuttle camera views
016	4	6 Apr 06	CMAS3 Surveillance (Dave & Nicole), Fracture fixation surveillance (Ron)
017	4	6 Apr 06	Education Outreach Event (PM)
018	4	6 Apr 06	CMAS3 Stryker view (Tim & Ron)
019	5	7 Apr 06	CMAS1 Surveillance (Tim) Part 1
020	5	7 Apr 06	CMAS1 Surveillance (Tim) Part 2
021	5	7 Apr 06	CMAS1 Surveillance (Nicole)
022	5	7 Apr 06	CMAS1 Face camera view (Dave)
023	5	7 Apr 06	CMAS1 Surveillance (Nicole & Dave)
024	6	8 Apr 06	Saturday Morning Science, MCHS Mirazyme Experiment, Habitat Tour, Habitat Tour for Roman, Ross w/ Moray Eel, Dave explaining 1/6g weigh-out
025	6	8 Apr 06	CMAS1 Surveillance (Tim)
026	6	8 Apr 06	ROV camera view – vehicle inspection
027	6	8 Apr 06	CMAS1 Surveillance (Dave & Ron)
028	6	8 Apr 06	CMAS1 Surveillance (Ron)
029	6	8 Apr 06	ROV ops (ROV camera view)
030	7	9 Apr 06	CMAS5 Surveillance (looking straight down)
031	7	9 Apr 06	CMAS5 Surveillance (looking straight down)
032	7	9 Apr 06	CMAS5 Surveillance (looking from side)
033	7	9 Apr 06	Dawn Dive (In water video)

034	7	9 Apr 06	CMAS5 Surveillance (looking straight down)
035	7	9 Apr 06	CMAS5 Surveillance (looking straight down)
036	8	10 Apr 06	CMAS2 (Ron) 10:30 Dr. Dobrinowski explaining the exploration relevance of this radiology experiment ends at 11:30, Wet porch suit-up for 3/8g CG experiment w/ exploration relevance comments (ends at 16:40)
037	9	11 Apr 06	Pre-Dawn suspected Grouper spawn outside main view port, singing happy birthday to Ross @ breakfast, Robotic lunar sample manipulation, tape left on until end by accident
038	9	11 Apr 06	ROV camera view (ExPoc driving on MD8)
039	9	11 Apr 06	Robotic lunar sample manipulation (straight-on view)
040	9	11 Apr 06	CMAS6 Surveillance
041	10	12 Apr 06	CMAS1 Surveillance (Tim)
042	10	12 Apr 06	CMAS1 Surveillance (Nicole)
043	10	12 Apr 06	½ way party videocom w/ ExPoc, watching "Life Aquatic" w/ Steve Zizou hats, Stella & Lucy out bunk room view port
044	11	13 Apr 06	Over cam of Dave & Ron building Waterlab on SL-17 (ROV bump)
045	11	13 Apr 06	CMAS4 Dave ultrasound and arthroscopy
046	11	13 Apr 06	CMAS4 Nicole arthroscopy
047	11	13 Apr 06	ROV cargo search, (Turtle fly-by @ 1:00:59) Atlantic Ray, Cargo found
048	11	13 Apr 06	CMAS4 Ron-arthroscopy, Nicole-ultrasound
049	12	14 Apr 06	ROV camera views (cargo vehicle recovery attempts)
050	12	14 Apr 06	ROV camera view during Waterlab construction (Dave & Nicole) ROV tool handoff
051	12	14 Apr 06	ROV camera view during Waterlab construction (Dave & Nicole) PLSS change out
052	12	14 Apr 06	ROV camera view during Waterlab construction (Dave & Ron)
053	13	15 Apr 06	UNL Vivo (Surveillance) (Dave)
054	13	15 Apr 06	ROV camera view Task Efficiency #1 (ROV grid search)
055	12	14 Apr 06	ROV camera views (cargo vehicle recovery attempts)
056	15	17 Apr 06	Education Outreach Events
057	15	17 Apr 06	Exploration Lessons Learned Tape #2
058	15	17 Apr 06	ROV camera views (night test)
059	14	16 Apr 06	Scuttle Bunny ROV (Easter ops)
060	15	17 Apr 06	ROV camera views

#### Appendix 8 : Exploration Objectives

One of the big objectives of the NEEMO 9 mission was to assist in the development of surface exploration procedures and to use the habitat and the mission to further the goals of the vision for space exploration. To that goal we have established exploration scenarios and objectives and have mapped every payload and science activity that we performed to these scenarios and goals. The aim is to make NEEMO a better analog platform with each successive mission. And just as it is the plan to have successive lunar missions to the same location so that we can build an infrastructure and increase the capability with each successive mission we want to use that same philosophy with subsequent NEEMO missions and continually build the capability and the fidelity of the exploration analog.

For N9 we have constructed the following surface exploration objectives document to ensure that we captured the lessons learned during the mission. This document was laminated and kept on the wet porch for review prior to exploration activities

<b>Activity MD Date Time (WHEN)</b>	<b>Exploration Scenario  (WHY)</b>	<b>Exploration Objectives  (WHAT WE WANT TO LEARN FOR SPACE EXPLORATION)</b>	<b>NEEMO Analog Objectives  (WHAT WE WANT TO LEARN TO IMPROVE THE NEXT NEEMO MISSION)</b>
<b>WaterLab</b>  MD-8 10 April 06 08:10 hrs ----- MD-11 13 April 06 08:15 hrs ----- MD12 14 April 06 08:45 hrs ----- MD 15 17 April 06 08:30 hrs	During the Apollo program there was no requirement for EVA crewmembers to communicate with their landing vehicle/habitat. Crewmembers during Apollo communicated directly to Earth. Due to the planned increase in lunar surface crew size, in the future it may be beneficial for crewmembers to have the capability to communicate to crewmembers remaining in their habitat while conducting surface exploration. The lunar horizon for an EVA crewmember is ~2.4Km. In order to communicate to the habitat while on excursions beyond 2.4km a comm. relay station will need to be constructed. A 20' (6.15m) relay tower would increase the communication range to ~9km.	10. What is the feasibility of an EVA crewmember operating in a lunar gravity environment to construct a 20' Comm relay structure 11. What is the feasibility of incorporating robotic collaboration during construction tasks 12. What lessons can be learned for the development of robotic collaboration with surface construction tasks 13. Evaluate what roles/assistance can IV crewmembers / MCC provide during surface exploration 14. Assess long duration effects of various CG configs	1. Assess long duration effects of various CG configs 2. Assess the utility of the variable CG PLSS rig 3. Does the PLSS rig create any discomfort 4. Does the PLSS rig cause any restrictions in movement
<b>Aquanaut Tracking DTO</b>  MD-9 11 April 06 14:05 hrs ----- MD 10 12 April 06 08:20 & 15:00 hrs	As the number and complexity of Lunar surface EVAs increase and as simultaneous excursions to different locations occur there may be an increased operational need to track EVA crewmembers while conducting surface exploration. Real time EVA crewmember locations can potentially be monitored from within the habitat and MCC which could potentially lead to a more effective use of limited EVA time and increased flexibility to respond to changes as new discoveries are made	1. Determine the usefulness of having real-time displays of EVA crewmember location 2. Determine the feasibility of having real-time displays of EVA crewmember location 3. Record all significant EVA tracking lessons learned	Determine the operability of the LinkQuest Diver Tracking System deployed on NEEMO missions. This will include checking out the Diver Tracking system and calibrating it to known points. Using CobraTac (mission profile generated by the ExPOC), LinkQQuest, and working w/ ExPOC, go to the known locations identified in the site survey exercise. 1. Does the direction a diver is facing have an impact on the reliability/accuracy of the system? 2. Is body shielding a problem? 3. How does reliability/accuracy vary with depth above the sea floor?

			<ol style="list-style-type: none"> <li>How much does location mapping vary from “true” in different sectors from Aquarius?</li> <li>Does system error build as distance from Aquarius increases? By how much?</li> </ol>
<b>ROV Vehicle Inspection</b> MD-6 08 April 06 09:10 hrs	Upon arrival on the lunar surface exploration crewmembers will most likely want to assess the capability and condition of their habitat prior to conducting EVA's and other exploration activities	<ol style="list-style-type: none"> <li>What procedures for habitat inspection via ROVs controlled from inside the habitat and MCC can be developed?</li> </ol>	Proper measures to ensure safety and avoid collision with the Aquarius habitat must be strictly adhered to.
<b>Cargo Vehicle Search &amp; Recovery</b>  MD-11 13 April 06 14:45 hrs  MD-16 18 April 06 12:35 hrs	As habitats are established on the lunar surface, re-supply will no doubt be a critical component of mission success. If cargo ships arrive on the lunar surface beyond the visual range of the crew while within the habitat an effective search plan will need to be developed. This plan should make use of the synergy afforded by human-robotic collaboration. The premise is that the CV landed safely in the vicinity of the crew's landing zone prior to the crew's arrival to the lunar surface and our sensors indicate that the CV is close by. If the “CV” cannot be located through the window a search plan will need to be developed. Because it's always safer to operate robotics in an extreme environment than EVAs, the search the first day will be done via ROV.	Objective is to compare the EVA/Diver task efficiency, to combined robotic position marking with optimized EVA/Diver recovery. Hypothesis is that the diver/robot combo will be the most efficient, but only if the robots operate with supervised autonomy or ground control. <ol style="list-style-type: none"> <li>What procedures/lessons learned procedures for human-robotic collaboration during search tasks</li> <li>Should search commence initially by solely robotic means</li> <li>If robotic search is unsuccessful should human participates be added to search those areas that are beyond ROV range (tether range)</li> </ol>	Objective: To compare task efficiency indices of human only versus robotic assisted EVA tasks by completing two scenarios of marker search and retrieval. Scenario 1 will employ human searching & marker tag retrieval; Scenario 2 will employ robotic marker locating/mapping, development of an optimal marker retrieval plan by ExPOC using robotic acquired marker location data, followed by collection of markers by EVA/Diver on subsequent dive. <ol style="list-style-type: none"> <li>Crew will pilot the ROV and search the inner zone in an attempt to locate the cargo vehicle</li> <li>If the cargo vehicle is located crew will plan for EVA retrieval the following day</li> </ol>
<b>EVA CG Assessments</b>  1/6 CG EVA  3/8 CG EVA	As surface EVA's increase in duration and EVA tasks increase in complexity, the center of gravity of EVA crewmember could have a large impact on EVA effectiveness and efficiency	Objective is to perform tests to assess optimal center of gravity (cg) location for best stability for task performance.  <ol style="list-style-type: none"> <li>How important is the location of CG to overall task performance and workload?</li> </ol>	A reconfigurable PLSS rig will be worn by the divers and cg. Locations (quantity = 6) varied by mass distribution changes within this PLSS cg rig. Stability to perform a variety of tasks will be assessed with a variety of cg locations.  <ol style="list-style-type: none"> <li>What is the optimum CG setting for task performance and workload</li> </ol>

<p><b>ROV for video-documentation</b></p> <p><b>MD-3</b> 5 April 06 08:00hrs (crew) 13:00 (ExPOC)</p>	<p>Photo/Video documentation is important to verify that procedures are accomplished correctly and to assist the development of future exploration procedures. Photo/Video documentation has traditionally required a large amount of crew time. Semi-Autonomous/Remotely Operated robots conducting photo/video documentation could potentially free-up crew members and enable a more efficient timeline</p>	<p>1. What is the feasibility of robotic photo/video documentation</p>	<p>During ROV Orientation:</p> <ul style="list-style-type: none"> <li>• Configuring to send real-time video from both ROVs to the ExPOC</li> <li>• Configuring to tape video onboard from both ROVs</li> <li>• Determine and record tether management protocols inside the habitat</li> </ul>
<p><b>ROV/EVA to map/survey an area</b></p> <p><b>MD-5</b> 7 April 06 08:30 &amp; 14:20 hrs <b>MD-9</b> 08:15</p>	<p>Prior to EVA surface exploration, robotic rovers could potentially identify high interest objects, map navigation routes, evaluate terrain in terms of required equipment and quantity of consumables, and also evaluate the condition of deployed consumables (if used) The first use of a robotic system during a lunar mission will include a checkout of the ROV, familiarity with operating the ROV on the lunar surface, data connectivity with MCC, and MCC operation of the ROV.</p>	<ol style="list-style-type: none"> <li>1. What is the feasibility of incorporating robotics to map surface features out to the tether limits of the ROVs?</li> <li>2. What detail can be added to existing maps using an ROV?</li> <li>3. How important is it to have detailed maps of excursion areas?</li> <li>4. Will we need excursion lines when the surface is obscured by numerous tracks?</li> <li>5. What ROV tasks can be controlled from the ground and what have to be controlled from w/in the habitat</li> </ol>	<p><b>SITE SURVEY ROV</b> Objectives (all on seafloor in rover mode): ExPOC exercise to determine whether they can add detail to the map by using an ROV.</p>
<p><b>ROV as a real-time MCC or IVA SA tool during EVA's</b></p> <p><b>H2O Lab #1, 2, 3</b></p>	<p>Video views from an ROV can be used during an EVA to provide real-time video views to MCC for MCC situational awareness. The use of a ground-commanded ROV allows MCC complete control over the camera positioning, zoom, and focus.</p> <p>The IVA crew could use an ROV for the same purposes.</p>	<ol style="list-style-type: none"> <li>1. How useful is it for MCC to have moveable real-time video during EVA's?</li> <li>2. How useful is it for MCC to have moveable video compared to stationary video camera views?</li> <li>3. How useful is it for MCC to be able to control the camera positioning and views?</li> <li>4. How do these same considerations apply to IVA control of ROV?</li> </ol>	<p>During WaterLab #1-3: In addition to talking with the crew and watching stationary video, the ExPOC will watch real-time ROV video to enhance situational awareness. The ExPOC will drive the ROV and control the camera onboard the ROV (positioning and focus). How effectively can the ExPOC control the ROV camera view given the underwater operating environment?</p>



<b>ROV performing advance lunar sample reconnaissance and/or collection</b>  <b>MD-3</b> 5 April 06 08:00hrs (crew) 13:00 (ExPOC)	An MCC-commanded ROV could perform initial identification, location, and photo documentation of potential lunar samples. The science team would then review this data and select which samples the crew or an ROV will collect at later time. An ROV could also acquire and retrieve lunar samples if it is equipped with the required capabilities (mobility and manipulator dexterity)	<ol style="list-style-type: none"> <li>1. Is it useful for the ROV to ID, mark location and photo document a sample of interest before sending EVA crewmembers to retrieve a sample?</li> <li>2. Is it advantages to conduct all activities including sample return to the habitat robotically?</li> <li>3. What ROV capabilities are required to perform these functions?</li> </ol>	During ROV Orientation for crew and/or ExPOC: The crew and/or ExPOC will locate, photo document and retrieve (if ROV capabilities allow) at least one sample. Does the ROV provide an adequate view to accomplish sample reconnaissance objectives? If not, what additional ROV capabilities are necessary? What ROV modifications or manipulator modifications are necessary for an ROV to collect samples?
<b>ROV as a real-time EVA assistant</b>  <b>Site Survey #1</b>	An ROV can carry lunar sampling tools, containers, and collected samples for an EVA crewmember. This reduces the physical load of the EVA crewmember and may increase the operational efficiency of the EVA.	<ol style="list-style-type: none"> <li>1. How useful is it for the ROV to carry tools and samples for a crewmember during an EVA?</li> <li>2. Assess the level of crewmember or MCC interaction with the ROV.</li> <li>3. Can a lunar ROV be driven by the MCC or does it have to be driven by the IVA due to time delays and/or safety concerns?</li> <li>4. What ROV capabilities are required to perform these functions?</li> </ol>	During Site Survey #1: If equipment is available, the ROV will carry a basket containing lunar sample tools and containers. The ROV will also carry the samples after they are collected in the containers. What ROV manipulator modifications are necessary for an ROV to function as a real-time EVA assistant?
<b>ROV to fetch a sample or tool</b>  <b>MD-3</b> 5 April 06 08:00hrs (crew) 13:00 (ExPOC)	Since EVA activities normally have a very compressed timeline due to limited consumables, idle time must be reduced to the minimum possible. As opposed to a crewmember walking back to a rover or habitat to retrieve a desired object, using an ROV for retrieval could potentially free up the crewmember to do other activities and allow a more efficient timeline	<ol style="list-style-type: none"> <li>1. What lessons can be learned for the development of robotic collaboration with surface construction tasks including using the ROV to fetch objects</li> </ol>	Use ROV to fetch a sample or tool for EVA crew Piloting objectives (ROV Orientation): <ul style="list-style-type: none"> <li>• Hovering</li> <li>• Grappling &amp; releasing</li> <li>• Transporting something</li> <li>• Providing "inspection" quality video</li> <li>• Gaining situational awareness of surroundings (including tether)</li> </ul>
<b>ROV to return something to the habitat</b>  <b>MD-3</b>	Since EVAs are potentially dangerous activities they should be avoided when other means to accomplish a task are equally suitable. Additionally EVA crewmembers face limitations that ROVs may not. ROV can traverse into tighter spaces and into	<ol style="list-style-type: none"> <li>1. What lessons can be learned for the development of robotic collaboration through the use of ROVs to avoid an EVA and/or to go where EVA crewmembers cannot</li> </ol>	Use ROV to return something to the habitat ideally from a location that EVA crewmembers cannot go (i.e. the surface or a tight confined space) Piloting objectives (ROV Orientation):

5 April 06 08:00hrs (crew) 13:00 (ExPOC)	situations of higher danger than is acceptable for EVA crewmembers.		<ul style="list-style-type: none"> <li>• Hovering</li> <li>• Grappling &amp; releasing</li> <li>• Transporting something</li> <li>• Providing “inspection” quality video</li> <li>• Gaining situational awareness of surroundings (including tether)</li> </ul>
<b>Impact of time delay</b>  Selected Activities	The lunar delay of a couple seconds will be incurred during all uplinks and downlinks. This includes audio, video, data transfer, and commanding. For which types of activities does this length of time delay become a consideration that impacts the methods used to conduct mission operations?	1. For which activities does the time delay lead to a change in methodologies used for mission operation?	Using NetDisturb software, the ExPOC will invoke time delays during selected activities. The ExPOC will record the impact of performing these activities with a time delay compared to no time delay.
<b>Data and Information Management</b>  Daily	During the course of a lunar mission, many types of data and information will be created and must be transferred between multiple users at multiple destinations. The management of this data and information will be essential to successful and efficient mission operations.	<ol style="list-style-type: none"> <li>1. What are sound methods for data and information management and transfer between mission participants?</li> <li>2. How does the available bandwidth affect the data transfers?</li> <li>3. What are the considerations when the same information is used by multiple participants and may be stored in multiple locations?</li> <li>4. How well do the scheduled data transfer times in the timeline work?</li> </ol>	<p>Due to the Aquarius computer network configuration, the crew will store different data on the NURC server and the ExPOC server. The ExPOC will transfer the data from the NURC server to the ExPOC server so that the ExPOC server has a complete set of data. In addition, data is provided to and from the crew via OSTPV, IPV, e-mail, and voice.</p> <p>How well does this multi-faceted system work?</p> <p>Benchmark the data transfer rates between NURC and ExPOC.</p>
<b>Crew Videoconferences</b>  Multiple Days	Lunar missions will have video conferencing capabilities. The limited bandwidth will necessitate a prudent use of video conferencing. Video may be used for conferences with MCC, scientists, crew families, PAO, and education outreach.	<ol style="list-style-type: none"> <li>1. What are the pros and cons of video conferencing compared to teleconferencing for mission conferences? For family conferences?</li> <li>2. For which activities is it the most advantageous to use video conferencing?</li> </ol>	Most DPC's will be held via 3-way video conference, but some will be held via telephone. What are the pros and cons of these two methods? PFC's are video conferences. Many PAO and Education outreach events use video at least one direction. When is it important to have two-way video vs. one-way video vs. teleconferencing?
<b>Lunar Sample Collection</b>  Site Survey	The EVA crew will collect lunar samples for return to the lunar habitat. The processes for documenting the location of the sample site, description of the sample, description of the site,	1. Given current technology and scientific understanding, what are reasonable methods for collecting lunar samples? What special	During Site Survey # 1 -3: Crewmembers will collect at least one sample. The ExPOC and crewmembers will record data during the activity. The crew will

#1 - 3	photo-documentation of both sample and site, as well as the physical sample collection methods will impact the results of the sample analysis.	<p>considerations are there?</p> <ol style="list-style-type: none"> <li>2. What are the pros and cons of reading information to MCC compared to the EVA crewmember writing the information down during the EVA?</li> <li>3. To what extent would interactive electronic procedures and voice recognition software aid or hinder the processes?</li> </ol>	take photographs. The data and photos will be transferred to the ExPOC; the ExPOC will transfer the data to the lunar scientists.
<b>Lunar Sample Processing</b>  MD-7	The IVA crew will use a robotic arm to process lunar samples inside the habitat. The methods used for this will impact the results of the sample analysis. The samples will also be photographed and videoed. The data will be transferred to MCC; MCC will transfer the data to the lunar scientists for further analysis.	<ol style="list-style-type: none"> <li>1. Given current technology and scientific understanding, what are reasonable methods for processing lunar samples inside the habitat? What special considerations are there?</li> <li>2. What robotic manipulator capabilities are required?</li> <li>3. Are digital photos and frames from video both sufficient for scientific documentation and analysis?</li> </ol>	During the Lunar Sample Analysis activity, the crew will use a robotic arm to process five simulated lunar samples that have already been collected. The samples will also be photographed and videoed. The data and photos will be transferred to the ExPOC; the ExPOC will transfer the data to the lunar scientists.
<b>CMAS 1</b> <b>Impact of Latency on Human Performance and Brain Activity</b> MD-2 4 April 06 MD-5 7 April 06 MD-6 8 April 06 MD-10 12 April 06 MD-11 13 April 06	On future lunar exploration extensive use of tele-operations including tele-robotics is likely. One of the major drawbacks of tele-robotics is the temporal delay in information & feedback that current telecommunications impose. This delay in combination with prolonged spaceflight is likely to produce significant stressors that will impact on neurocognitive function and performance.	What effect does latency, inherent in space communications have on human performance and normal brain activity	Evaluate the effect of different feedback latencies on surgical / tele-robotic performance measures and EEG recordings during both stressful and non-stressful environmental conditions

<b>CMAS 2</b> Digital Radiology Validation  MD-8 10 April 06 10:00 & 13:25 hrs	<b><i>Acute Surgical / Medical / Orthopedic conditions can occur during space exploration. Confirmation of clinical diagnosis with x-rays is an important step for deciding upon the appropriate treatment and mission impact.</i></b>	What is the quality of digital radiographs which have been transmitted from an extreme environment over a simulated lunar network.	Determine the quality (contrast and spatial resolution), and adequacy for clinical interpretation of radiographs transmitted from an extreme environment over a simulated network.
<b>CMAS 3</b> Emergency Treatment of fractures using orthopedic modalities and telementoring  MD-4 6 April 06 07:45 – 12:15 hrs	<b><i>During space exploration activities minor or severe body trauma is a distinct possibility. There may be a need for a crew member to treat a previously identified bone fracture with pins or external fixation.</i></b>	Can we demonstrate that an emergency treatment of a forearm bone fracture can be accomplished by a non-physician or a non-specialist aided by telementoring in an impaired network that mimics lunar exploration latencies (2 sec delay)	This test will evaluate whether a non-physician or a non-specialist physician can properly reduce a bone fracture aided by an expert using tele-mentoring
<b>CMAS 4</b> Emergency Treatment of joint injuries using ultrasound, arthroscopy and external fixation using telementoring MD-13 15 April 06	<b><i>During space exploration activities minor or severe body trauma is a distinct possibility. There may be a need for a crew member to identify and treat a joint injury.</i></b>	Can we demonstrate that an emergency treatment of joint injuries can be accomplished by a non-physician or a non-specialist aided by telementoring in an impaired network that mimics lunar exploration latencies (2 sec delay)	This test will evaluate whether a non-physician or a non-specialist physician can properly identify joint injuries and repair meniscal injuries using an arthroscope or external fixation for joint dislocations.
<b>CMAS 5</b> Evaluation of tele-robotic technologies for extreme environments and lunar exploration MD-7 9 April 06 11:00 – 13:00 hrs	<b><i>Provision of emergency surgical care in an extreme environment has usually required the transporting of the often unstable patient to an emergency surgical facility or else transport the surgeon to the site. Transporting an injured or ill crewmember to a medical facility is not usually feasible during space flight. Crew survivability and mission success will be greatly enhanced if alternatives to medical evacuation can be found</i></b>	<b><i>Evaluate the ability for a remote surgeon to perform an emergency surgery using tele-robotics while subjected to terrestrial and lunar latencies</i></b>	Objective is to use tele-robotics to enable a remote surgeon to perform a surgical operation which may be required on an emergency basis in an extreme environment.

<b>NSBRI Substudy #1:</b> <b>Linguistic, Physical, and Cognitive Indices of Group Process and Interpersonal Communication in Remote, Isolated Environments</b> MD-X XX April 06 Xx00hrs	Long duration space flight can lead to problems associated with group dynamics. It will be critically important for crews to continue to work together effectively in spite of being confined to small spaces far from Earth for long periods of time. Group dynamics ( language, physical cues, and implicit cognitions.) may indicate constructs such as leadership, information-sharing, dominance, or situational awareness. Group Dynamics factors can possibly predict team breakdown or task failure.	Objective is to glean correlates and/or predictors of relative task performance (e.g., success/failure) as indicated by quantitative and qualitative analyses of language use, physical activity flow, and measures of implicit interpersonal cognitions.	Same as Exploration Objectives
<b>NSBRI Substudy #2:</b> <b>The Effectiveness of Embedded Cognitive Performance Readiness Measures in a Telemedicine / Telesurgery Spaceflight Analog Environment</b> After CMAS1 & CMAS4	In spaceflight, astronauts will be required to do many different critical tasks with associated stress factors. The development of embedded performance tests that can be successfully related to performance readiness metrics will give the astronaut and mission control information on the best time to perform critical events and an evaluation of the need for countermeasures.	Test the usefulness of embedded task performances as dependent measures of the effects of cognitive readiness and stress. In addition, this project will provide proof of concept for computerized optical recognition as a stress-related performance readiness measure.	The two cognitive measures will be the MiniCog/Rapid Assessment Battery (MRAB) and the Perceptual Vigilance Test (PVT). Both tests contain tasks that allow investigators to distinguish between the effects of stress and fatigue on performance. The two measures of stress will be cortisol level and computerized optical recognition metrics.
<b>NSBRI Substudy #3:</b> <b>Team Cohesion and Productivity, Stress Indicators, Readiness to Perform</b>  Daily Asmt– daily TLX after CMAS1&4 AMS – MD2, MD3, MD8, MD11, MD13, MD 16?	Long duration space flight can lead to problems associated with group dynamics. It will be critically important for crews to continue to work together effectively in spite of being confined to small spaces far from Earth for long periods of time	Assess group development, communication structure, cohesion, problem-solving and decision-making strategies over time in a confined and isolated environment. Test the ease of use, utility, and decrements in a voluntary creativity task. Associate measurements with physiological readings from the ambulatory monitoring system (AMS) physiological recording system data	Study the individual astronaut and crew looking at performance readiness, stress levels, and effectiveness as a team. Provide information so that the researchers can learn how to improve and refine real time monitoring and develop predictive models that can be tested in other analog studies, with the eventual goal of having a suite of tools that astronauts can use in spaceflight.

<b>NSBRI Substudy #4:</b> <b>Sleep/Wake Actigraphy and Light Exposure Measures in an Extreme Environment</b>  Daily	The success and effectiveness of manned space flight depends on the ability of crewmembers to maintain a high level of cognitive performance and vigilance while operating and monitoring sophisticated instrumentation. Astronauts, however, commonly experience sleep disruption and may experience circadian phase misalignment during space flight. Relatively little is known of the prevalence or cause of space flight-induced insomnia in short duration missions, and less is known about the effect of long-duration space flight on sleep and circadian rhythm organization.	The objective of this study is to better understand the effects of space flight conditions on performance and sleep, and will aid in the development of effective countermeasures for both short and long-duration space flight.	Crewmembers will don an actiwatch daily to monitor sleep-wake activity patterns and light exposure. Subjects will also complete a brief daily written evaluation of their sleep quality and daytime alertness.
<b>NSBRI Substudy #5:</b> <b>Psychophysiological Measures During Confinement in an Underwater Habitat</b>  Williams – MD3, MD11, MD16? Garan – MD2, MD8, MD 13	During certain phases of long duration space flight it may be required to monitor psychophysiological measures on individual crewmembers. The means to measure this data cannot interfere with the crew's ability to function effectively.	Obtain human physiological data of crewmembers during normal working hours while evaluating ambulatory monitoring system (AMS) signal quality, ease of operation, and crew comfort.	Determine if measures can be taken within the habitat. Correlate physiological data to workload of scheduled tasks. Amass a baseline database of behavioral observations; this can be used for the development of automatic analytical procedures to track performance readiness and health of crews working in isolation.
<b>U of N Substudy</b> <b>Miniature In Vivo Robots for Tele-Surgery in Extremely Remote Environments</b>  MD-3 05 April 06 13:00 & 16:00 hrs MD-4 06 April 06 16:25 hrs MD-15 17 April 06 13:55 hrs	During long duration space flight medical diagnostic systems will be critical to effective telemedicine applications. Medical imaging equipment will need to be as small and light weight as possible to effectively be deployed on spacecraft cargo manifests.	Current surgical robots are large and require extensive support personnel. Therefore, their implementation has been limited in extreme environments.	Two systems will be evaluated: 1) a mobile robot with a remote imaging system, and 2) a pan/tilt imaging system. Both devices are remotely controlled and can provide in vivo images from multiple viewpoints. The objective is to compare the use of <i>in vivo</i> imaging systems to standard laparoscopes and evaluate their usefulness for tele-surgery.

<b>General Things to Investigate</b>	<ol style="list-style-type: none"> <li>1. What is the feasibility of tethering life support to a rover</li> <li>2. How important is it to have deployed consumables</li> <li>3. Another exploration objective that we may be able to comment on based upon NEEMO 9 is the capability for habitat maintenance. In N9 the Hab Techs will be going outside the habitat using HOOKAH to maintain the habitat exterior. For lunar habitats – <ol style="list-style-type: none"> <li>a. Will exterior maintenance be required?</li> <li>b. If so, will we use a full planetary exploration suit with a PLSS or is there an opportunity to have breathing gas supplied from the habitat via umbilical with hardline communications back to the habitat.</li> </ol> </li> <li>4. Another exploration question is the deployment of navigation beacons, or antennas on the lunar surface to enable accurate lunar navigation and astronaut tracking.</li> </ol>		

## Appendix 9: Cue Cards:

GEN EVA Rev-A: 9/17/2004

### Generic EVA Reports

#### **EVA start/end:**

- Visibility  
(Poor<20, Fair<50, Good>50)
- Intensity of current  
(calm, mild, moderate, severe)
- Direction of Current

#### **Every 45 minutes:**

- Tank P
- Exertion Levels  
(low/med/high)
- Team Location \*
- Team Depth
- Intensity of Current
- Landmarks / Terrain Features

#### **At tank refill**

- Pre-fill time and Tank P
- Post-fill time and Tank P
- Refill location

#### **CAUTION:**

Min depth is 40 ft.  
Max depth is 95 ft

#### **\* Team Location Data:**

- Distance out line
- Distance from line
- Bearing from line
- Team Depth
- Landmarks / Terrain

**Warning: Do not keep Steady flow valve open with EGS unless absolutely necessary**

### Generic EVA Brief

#### **Egress Plan:**

- Buddy Pairs, Buddy Leads
- Safety Checks on Wet Porch
- Additional Science Dive Equipment

#### **EVA Plan:**

- Excursion Line
- Excursion Depth Limits
- Final Dive Site
- Cave Reel Plan
- Comm. Plan
- Task Review
  - o Get Ahead Tasks
  - o Constraints
- Photo-TV Requirements
- Visibility  
(Poor<20, Fair<50, Good>50)
- Intensity of current  
(calm, mild, moderate, severe)
- Direction of Current
- Bingo Tank P
- Fill Location (Habitat/Way Station)
- Check-In Time
- Habitat Return Time

#### **XPOC Check-In Every 45 minutes:**

- Tank P
- Exertion Levels (low/med/high)
- Team Location
- Team Depth
- Intensity of Current
- Landmarks / Terrain Features

#### **At tank refill**

- Pre-fill time and Tank P
- Post-fill time and Tank P
- Refill location

#### **Emergency Procedures:**

- Dive Abort Criteria
  - o Diver Recall
  - o Failure of Breathing Gas
  - o Failure of BCD
  - o Personal Equipment Failure
  - o Watch Failure
  - o Dive Light Failure
  - o Comm. Unit Failure
- Lost Buddy

### MK48 Preflight

#### **Exterior:**

- ✓ Comm wires
- Connect battery wires
- Wet Mate High-Use Connector
  - o Solid Light – System On
  - o Blinking Light – Batt Low

#### **Check Comm Settings:**

- Triple Click: Present settings  
(PTT / Ch-1 / Sqlch-On / Vol: Side-HI, Receive-HI)
- Double Click: In/Out of Menu

#### **Troubleshooting**

Can't Transmit/Receive

- ✓ Red Light - On
- ✓ Battery Wire Connected
- ✓ Mate/Demate Hi-Use Connect X 2
- ✓ Menu Settings

#### **Considerations**

- Don't change depth with flooded mouth pod

#### **Postflight**

- Rinse MK-48 and transmitter in fresh water
- Dry w/ towel ensure red light – out (~5min)
- Disconnect Battery after every dive
- Clean & Lube O-ring each battery change



### **Superlite Emergency Procedures**

#### **Helmet Flooding:**

1. Assume upright position (tilt head left)
2. Fully open Steady Flow Valve
3. Report condition
4. After clearing water check for leaks (close steady flow valve)
5. If helmet continues to take on water – Steady Flow Valve as required
6. Abort Dive

#### **Excessive Breathing Resistance:**

1. Turn dial-a-breath out (CCW)
2. If still excessive – open steady flow valve
3. If still excessive – press purge button during inhalation
4. If still excessive – open EGS
5. Report condition
6. Abort Dive

#### **Umbilical Gas Supply Failure:**

1. Check Dial-A-Breath while opening EGS
2. Report Condition
3. Abort Dive

#### **Fouled or Pinned Umbilical**

1. Report condition while attempting to remedy
2. If unable wait dive supervisor instructions

### **Superlite Preflight**

#### **Inspect Helmet Exterior:**

- Correct color designation
- No cracks or damage
- No deterioration in shell O-Ring
- O-ring properly seated in helmet groove
- Inspect faceplate
- Inspect bent tube assym (no kinks/dents)

#### **Inspect Neckdam:**

- Correct color designation
- No tears, deterioration, or seams

#### **Inspect Helmet Interior:**

- ✓ Oral-Nasal Assembly
- ✓ Comm connected
- Head cushion dry and properly fastened

#### **Inspect and Purge Umbilical Gas Supply**

- Umbilical-no cracks, bulges or FOD

#### **Superlite Setup**

- Connect umbilical to inlet on side block
- Connect umbilical comm. Cable to helmet
- Slowly pressurize umbilical gas supply
- Connect EGS hose to side block EGS valve
- Open EGS cylinder valve & record pressure
- Ensure EGS gas flow to side block
- ✓for leaks

#### **Don Superlite:**

- Don Weight Belt
- Don EGS Harness
- Pull helmet oral nasal assym all the way out
- Adjust dial a breath all the way in (CW)
- Ensure Steady Flow valve closed
- Slowly pressurize helmet
- Don helmet
  - o ✓ Secure
  - o ✓ neck clamp latched &secure
  - o ✓ nothing across O-ring
- Comm Check
- Check Helmet EGS valve - Closed
- Open steady flow valve, then close
- Press regulator purge button
- Turn dial-a-breath out until slight free flow then in approximately 2 turns

#### **Surface Check**

- ✓ EGS Valve - Shut
- ✓ Steady Flow
- Adjust Dial-A-Breath
- ✓ Purge Valve

#### **In Water Check**

- Surface Check plus leak ✓ & push in oral nasal
- ✓ Weigh-out

#### **Superlite Postflight**

- Before doffing helmet
  - o Pull out Oral-nasal
  - o Dial-A-Breath – All the way in (All the way out for stowing)

## Appendix 10: Living and Working on Aquarius

### A Simple and Fun Reference for Future NEEMO Crews



Look out the viewports!!!!



#### Habitat Technician Crewmembers:

These guys are great. You will find very quickly that they are vital to your mission success. They know the habitat, they know dive ops, and they know how to live in Aquarius. They will help you in every way they possibly can. Respect their expertise, respect the tasks they are responsible for, and take advantage of the guidance they can give you while you're living and working on Aquarius.

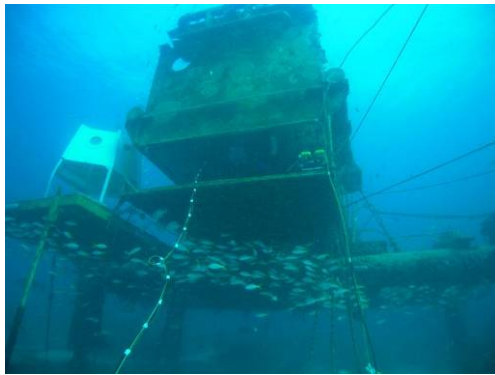
They are required to report all kinds of things to the watch desk – some that may seem insignificant to you, but can get them in trouble topside if they don't do it. They do this primarily via a chat format on the computer and via the phone. Some of the things they need to report are gazebo departure and return times, any meds taken, dive excursion start and end times, and anything else they ask you to tell them. Please be very conscientious about supporting them with this info.

One of the things you might be faced with during a dive is needing additional time for a specific task. First of all, don't exceed your planned dive time. Always give yourself some pad to get back to the habitat on time – always maintaining situational awareness during the dive will also give you the opportunity to ask for an extension. Your habitat technician crew members will have to get the "go" for an extension from topside, so don't just assume this will happen. But you can expect them to be pretty flexible as long as they see that you are diligent about how you manage your time.

#### The Potty:

#1 – Unless you're in the water, this is just like camping, only you're in the Wet Porch hanging over the water. There is a camera in the Wet Porch that only the watch desk can see; however, it is easy to strategically place yourself out of the field of view of the camera.

#2 – This is one of the things pre-mission that seems pretty mysterious even if you speak to past crews. Think it's safe to say though that once you do it the mystery is gone. You swim from the wet porch to the gazebo to perform this operation. It is VERY important to let your habitat tech crew members know when you are going to the gazebo and when you get back so they can keep track of where you are and let the watch desk know. It's only a short swim (maybe 5 feet) between the habitat and the gazebo; you only need to wear a mask (and your crewmembers will probably prefer you wear a bathing suit too), but some also suggest wearing your booties.



Try to avoid grabbing the habitat structure or floor grates with your bare hands to avoid scraping yourself. You've heard about the poop-eating fish – it's true. They are Chubs and Angelfish. They are not small. There are a lot of them. They are generally not aggressive, but they are also not afraid to get up close and personal. You will discover a position that works best for you, but suggest you incorporate some kind of continuous sweeping motion in front and behind you to discourage any unwelcome contact from an impatient fish. There is a camera pointing at the gazebo, but you can't really see anything and as you can imagine no one is really interested in getting that much information about you anyway.

#### The Shower:

The shower will always feel great, and you will take one every time you come back from a dive or post gazebo ops. The water can get very hot, so be careful. Also watch out for the hot water pipe that runs along the wall – it's easy to bump into – it was covered when we were there which made it less of a problem. Follow your habitat tech crewmembers directions for using the shower (just like you should follow all their other directions in the habitat). The fresh water comes from the surface and is limited, so everyone takes navy showers – turn water on, get in and rinse off, turn water off, lather up, turn water on and rinse off, the end. They will provide shampoo and soap. The liquid soap they provide is Dr. Bronner's Peppermint soap and it is wonderful – aside from working really well, it smells great and helps relieve some of the odor in the wet porch that will develop from the urine soaked wetsuits, no matter how well you think you've rinsed them out. Yeah, yeah we know you don't pee in your wetsuit....



Also, take advantage of your shower time to give your skin a good once over so that you can stay ahead of any irritation that might develop. Your stinky wetsuit and the generally moist environment make skin problems more likely and you want to be sure to address them quickly. If you do notice any skin irritation, cuts or scrapes, be sure to let someone know so you can treat it aggressively – Neosporin and Desitin are your friends.

#### Food:

You only have a microwave oven and instant hot water heater for preparing food, but they work great for what you'll need. Again, be sure to follow your habitat technician crewmembers directions re: the microwave, and always turn the timer to zero before opening the door. And the water from the instant heater is REALLY hot, so be careful. Overall the Mountain House dehydrated food is pretty good, but be sure to take advantage of your pre-mission shopping trip to get some additional stuff you'll like. As with spaceflight, your friend is the tortilla. We also found tortilla chips with melted cheese were a big hit! Hot chocolate was also really good for a quick warm-up after a dive.

Also, never ever ever put a drink or food on the starboard counter in the crew lock!

#### Temperature:

The habitat is kept pretty cool (~72 F) to help manage the humidity. This will seem even cooler to you after you've been diving all day. Be sure to bring a sweatshirt or fleece top, and sweatpants to wear. We would also suggest something warm for your feet. MaryJane Anderson and the friendly folks in Flight Crew Equipment can help you out with some nice sock booties like the ones used on orbit. Just be sure to give them enough time to get them ordered for you. Also, it seems even colder at night in the bunks – suggest bringing some kind of ski cap to keep your head warm.

#### PFC:

Private family conference / personal family conference --- whichever of these your family will be told the 'P' stands for does not necessarily reflect the way the videoconferences are held. Maybe we should just lose the P and call them family conferences. There is really no way to make these private --- at least not from the habitat side of things. So it's worth letting your family know up front that they won't have you all to themselves. Your crewmates will have other activities going on in the habitat and even though they will try to stay out of your way they don't have far to go. Also, if your family chooses to go to the Wyle building for their end of things, they will be in a big conference room and there will be operators monitoring the picture to ensure things are working. It will make it much easier and less stressful on both ends if the family

knows this. There are other options that can be worked with family support – e.g., setting up video conference capabilities on your home computer. Also, some crew members and families might find it easier to just have an extended phone conversation and pass on the video. Be sure to offer the family videoconference option to your habitat technician crew members too, and include these on the timeline if they want to have them.

## Appendix 11: Crew Recommendations

**Recommendation 1:** *Take all necessary steps to ensure that the entire topside contingent works together as one seamlessly integrated team. Improve communication between all members of the topside team and ensure all necessary personnel are working together in a coordinated manner with all mission activities. Eliminate multiple points of contact between the crew and topside team.*

**Recommendation 2:** *The Crew and Topside support team should work together permission to establish a working mission protocol for all mission communication responsibilities and operations.*

**Recommendation 3:** *If the preliminary JSC training at NURC is not possible for future crews, we strongly suggest scheduling crew dive training activities at the NBL. Practicing dive skills at the NBL should be done anyway, but more structured crew activities coordinated with the NBL divers would be very beneficial; especially in light of the reduced SCUBA that will be happening with several of the upcoming missions. Every effort should be made to ensure comfort level with SCUBA skills prior to participating in the pre-mission NURC training.*

**Recommendation 4:** *Provide the crew with a copy of the timeline for their review prior to this training week. This will help the crew be better prepared for the timeline review during the training week. The timeline review should include representatives from as many of the support groups as possible, and should include a discussion of the overall operations protocol.*

**Recommendation 5:** *Remove the briefing on the CB Expeditionary training flow from the schedule. All of the CB crew members participating on NEEMO will be familiar with this flow, and it has no impact on the non-CB crew members.*

**Recommendation 6:** *Continue to provide simplified standard practices for things like Photo/Camera Management. Each crew will appreciate having and will most likely work to this standard, and then will be able to modify as necessary during the mission.*

**Recommendation 7:** *Provide as much hands-on time with available hardware and the associated procedures as possible (to include training events like the CobraTac and camera practice we were provided).*

**Recommendation 8:** *Provide a scheduled meeting with the previous NEEMO crew. This was not a scheduled event for our crew so we arranged it ourselves. We only had an hour over lunch with a couple of the NEEMO 7 crew members, but it was very beneficial – a scheduled event will be even more valuable.*

**Recommendation 9:** *Provide a thorough Habitat overview including lessons learned from previous missions regarding stowage, computer setup, experiment setup, living arrangements and description of different modules. Although it*

does not cover all of these details, “Appendix 11, Living and Working on Aquarius” is a very useful reference and should be made available as soon as possible for future crews. Something like this would have been extremely useful for us. Other reference material such as the NOAA Technical Diving Manual and a textbook on scientific diving techniques should be available within CB.

**Recommendation 10:** Incorporate a crew dive session at the NBL. In addition to basic SCUBA skills, practice at the NBL with tools like CobraTac and the cameras. It should be easy to develop short scenarios for practice in the NBL with the CobraTac and taking pictures with the camera/strobe and video camera.

**Recommendation 11:** Crew should practice the different swimming skills for the swim test and get comfortable with them before going to Key Largo. The support of the commander is very important in crew participation in fitness training prior to and during the mission. The ASCR team at JSC and the ARF may be used to help prepare crew members.

**Recommendation 12:** All future NEEMO missions should include SCUBA-based EVA training and mission EVA’s

**Recommendation 13:** All crew training should be completed three days prior to Splashdown. The two days prior to Splashdown should be completely free of training to permit final mission preparation. However, this final mission preparation should not include putting the crew in a position of still needing to ensure procedures and other support materials are correct and complete. The preparation process for NEEMO missions needs to improve with respect to ensuring that the process adequately incorporates validation of all procedures and support material – the crew should of course be involved with this ahead of time, but not responsible for ensuring it is complete – this is the role of the topside support team. The weekend before splashdown should simply be a time for the crew to relax and review the plan for their mission.

**Recommendation 14:** Due to the potential mission impact of illness immediately prior to the mission, the Space Life Sciences Directorate should be consulted to determine what type of quarantine and primary contact (PC) program would be reasonable for a NEEMO mission. The program could be as simple as having the crew use hand sanitized frequently and having a voluntary PC program that reduces contact between individuals that are ill and the crew. PC physicals of individuals in contact with the crew may not be necessary.

**Recommendation 15:** Having at least one or two back-up crew members available for NEEMO missions is worthwhile. This was the second NEEMO mission in which a Commander was medically disqualified within weeks of the mission. In addition to multiple backup crew members, there should be an increased participation in training activities by the backups.

**Recommendation 16:** The NEEMO program should have sufficient resources to incorporate similar technologies in Aquarius to those used on the Shuttle and Space Station. The availability of A31P computers with wireless networking

**capability would reinforce for crew the IT skills required for spaceflight. A PGSC plan similar to that used in Shuttle missions would be of benefit for NEEMO.**

**Recommendation 17: Individual SD memory cards should be provided to each crew member with an expansion slot for the IPAQs. This provides a mechanism for each of the crew to bring digital photos of their family and a personal selection of music as behavioral support tool during the mission**

**Recommendation 18: Crew members should have a basic familiarity with computers and information technology. In more complex, longer duration missions, more advanced IT skills in at least one crew member is desirable.**

**Recommendation 19: Access to IT expertise within topside, NURC and collaborating academic/industrial partners during mission is critical. Access to topside experts should follow established protocol (via "MCC") to insure exploration analogue.**

**Recommendation 20: Thin clients and large storage size flash drives should be used on future missions. This combination is especially useful when large file transfer and data backup is required such as in photo management. Each crew member should have at least a 1 GB USB flash memory stick for file transfer during the mission.**

**Recommendation 21: Upgrade computer hardware as funding permits.**

- d) Select standard laptop (IBM A31P) for multipurpose use based upon optimal combination of speed, storage, I/O ports, and ruggedness. Standard laptop will remove conflict of use, facilitate trouble shooting, and allow easy replacement in case of failure. As funding permits, at least two identical laptop computers should be configured with identical mission, exploration, and science software for use in Aquarius. An additional laptop should be available topside to assist with troubleshooting and to serve as replacement laptop if needed during mission.**
- e) Consider upgrading IPAQs to tablet PCs for individual crew member use. If IPAQs cannot be upgraded, we do not recommend continued use of individual PDAs during mission. Journal can be typed on laptops or thin client. Nano IPODs can be used to listen to music as needed.**
- f) Use of standard laptops without IPAQs also will decrease supporting equipment such as chargers, com adapters/cables, portable keyboards, etc.**

**Recommendation 22: Use standard software on all laptops to decrease familiarization/training, simplify procedures, improve troubleshooting, and provide redundancy. Remove all unnecessary files, software, viruses, spyware, etc. before departing for Key Largo. However, ensure all data from previous missions has been saved before software removal.**

**Recommendation 23: Confirm consistent, expected performance of hardware/software before departing for Key Largo.**



**Recommendation 24:** Encourage investigators to use standard NEEMO hardware/software. If not feasible, critical science computer should have back-up either in habitat or NURC base.

**Recommendation 25:** As much as possible, all familiarization and training should be done on standard laptop in mission configuration.

**Recommendation 26:** Consider greater use of wireless network in future missions (80211.g, 80211.n and Bluetooth). Use of the wireless network in the habitat would allow hardware use at the point of need and avoid long Internet cables that present risk to crew and hardware. In addition, wireless would decrease hardware and personnel crowding by jacks in the entry lock and bunkroom.

**Recommendation 27:** If time is allotted in the schedule for photo management, it should be at the end of the day. Otherwise the crew will do this during their pre-sleep timeframe.

**Recommendation 28:** Increase the number of Sony cameras to at least three and use for all activities requiring video documentation

**Recommendation 29:** Include about 45 minutes in the crew timeline at the end of the day to accomplish video tape administration

**Recommendation 30:** Fully integrate the topside (JSC NEEMO) team with the ExPOC team into one functional team that communicates among the team in such a manner that's seamless to the crew.

**Recommendation 31:** Incorporate a NEEMO CAPCOM that is the sole individual to communicate with the crew during ExPOC/Topside Team supported operations. Ideally this CAPCOM should be an astronaut who is a previous NEEMO crewmember or one of the back-up crew assigned to the mission.

**Recommendation 32:** ExPOC/Topside Team should treat all future NEEMO missions as actual exploration space flights. Specific recommendations are:

- a. The Topside team should function as ONE team --- one team that just happens to consist of a control center (ExPOC) and local support (NURC/NASA topside). Integration is key for maximizing SA for everyone and for maximizing effective communication with the crew.
- b. Research all of the crew's technical questions that arise during the mission and formulate a timely response after conferring with experts (as opposed to suggesting that the crew contact experts directly).
- c. Establish and follow flight rules for all exploration activities.
- d. Establish and follow certification requirements for specific ExPOC control room positions and activities (i.e ROV ops, CAPCOM, etc.) and provide the associated training.
- e. Develop and communicate a fully coordinated plan for each day's activities. Ensure that these plans are fully coordinated with all

*members of the topside team to include the NURC staff. Do not ask the crew to plan the following day's activities during their pre-sleep activities*

- f. Adhere to strict console communications protocol that follow operational space flight protocols including:*
  - Never leave the crew without a quick response to comm. Therefore, never leave the console unattended, and be prepared to drop all other conversations when the crew calls and respond immediately to them. The crew should never wonder if there is someone on the other end of their call.*
  - If you don't have an immediate answer to a crew question, there are 2 possible responses:*
    - "Stand by" – means you know you can get the answer quickly enough that you're expecting the crew to stop what they're doing and "stand by" for your answer before proceeding.*
    - "We'll have to get back to you" – means that you will have to go track down an answer and it's going to take some time. In the meantime, you will need to provide the crew with feedback on how to continue the task without the answer or to redirect the crew to another task.*
  - Clear repetition of call signs and slowly spoken call details or response.*
  - Anticipation of crew questions/responses based on task being performed (e.g., GCA task to find transponders --- know what GCA means and that the crew is going to expect you to be proactively providing it).*
  - Based on SA, know if it is likely you'll get a response from the crew when you ask them to repeat or if it's even important enough to ask the crew to repeat.*
- g. Ensure all topside members are fully aware of the crew timeline and the impacts of checking-in late for planned DPCs and/or not being prepared to discuss the plans for the day*
- h. Record all data being collected to include video feeds and transcripts of transmitted data points (even if the crew is also recording the data).*
- i. Adhere to the 5 P's (Proper Planning Prevents Poor Performance)*
- j. Always strive to be at least one step ahead of the crew.*
- k. Anticipate questions and have the answers ready.*
- l. Have all the supporting information available to support crew implementation of the task (especially in situations where the crew can't have these in front of them themselves, i.e. out on a dive).*
- m. Know the task – for all procedures know who does what and why (e.g., where we had some problems with the ROV procedure).*
- n. Have all procedures open on console and actively be following along with the crew.*
- o. Know who the experts are and be able to contact them quickly for support (ideally they would be supporting on console too).*
- p. Situational Awareness is key!*

- q. *Know the limitations/overhead associated with the equipment the crew is using (e.g., ptt button on comm masks; swimming with the CobraTac; cave reel ops...)*
- r. *Know all the “knowns” about the territory the crew will be operating in (e.g., excursion lines; approximate bearings/ranges associated with all known features...).*
- s. *Know dive operations/safety limits and how what you’re asking the crew to do impacts them (e.g., picking up and carrying heavy weights; replanning a dive in the middle of the dive...)*
- t. *Establish and operate within “flight” rules. All of the above examples fall within this category of flight rules, as well as things like operator qualifications for ROV ops.*

**Recommendation 33:** *An improved method is required to protect the battery cable from Cobratac once the battery is disconnected.*

**Recommendation 34:** *A serial cable extender needs to be incorporated to go from the Cobratac download cable to the back of the computer.*

**Recommendation 35:** *For Navigating Menus a definitive answer needs to be found to the following question: If useable data was recorded is it required to go back to the main screen before powering off CobraTac?*

**Recommendation 36:** *The internal CobraTac software should be upgraded with a direct GO TO capability and real time truth update features. In other words the capability should exist to update the CobraTac’s state vector by “marking” on known locations.*

**Recommendation 37:** *There should be a reminder in the training and procedures about how the screen goes into a blank standby mode ----- therefore, power is still on and you can risk draining the battery if you don’t recognize this. The documentation says that the screen will have a light glow to it when it is in this mode, but none of us could tell the difference from when it was off.*

**Recommendation 38:** **DOWNLOAD PROCEDURES** - *When putting execute notes in the OSTPV activity details, these notes should clearly reflect the kind of data download they are asking for and the words used should match the words used in the appropriate section of the procedure. Also, there should be clear direction regarding deleting any data.*

**Recommendation 39:** **GRID MODE** - *When pushing “Start” do not begin using CobraTac to navigate until “Start” changes to “Leg”. This was the only indication that was observed to indicate that the Grid Mode was active.*

**Recommendation 40:** *Provide an overlay of Aquarius and the adjacent reef. This will enhance IV situational awareness of the location of either the crew or ROV to known points on the reef.*

**Recommendation 41:** Crew requests for media, PAO, and educational outreach activities should have priority when the schedule of events is established for the mission.

**Recommendation 42:** Continue to offer the opportunity for video conferences with our families. However, recommend we just call them Family Videoconferences, not Private or Personal Family Conferences (PFC). There is no way for these to be private and we shouldn't give the families the impression that they are.

**Recommendation 43:** Your Habitat Technicians are members of the crew and have families too. Include the videoconference option for them as well and make sure it is scheduled on the timeline.

**Recommendation 44:** Experiments should use standard NEEMO laptops as opposed to the Apple laptop. If it is not possible to use EEG software loaded on standard hardware, recommend back up laptop in the habitat or NURC base ready in case of hardware failure. Also recommend back-up amplifier. General recommendation for use of standard hardware and software is detailed below.

**Recommendation 45:** Consider modifying VR tasks more closely approximate telesurgical tasks.

**Recommendation 46:** Consider reducing the amount of large and heavy equipment that is potted down to Aquarius in support of this type of experiment. The important aspect of this experiment was primarily the evaluation of the radiographs, and this could have been performed successfully without any of the equipment or perhaps with something as simple as cardboard mockups. (However, continue to pot down the foot and arm).

**Recommendation 47:** Strongly recommend to continue externally funded, collaborative science in future missions.

**Recommendation 48:** Proxy science training and research of value to crew and should be encouraged in future missions.

**Recommendation 49:** As much as possible, use standard NEEMO hardware and software to complete science.

**Recommendation 50:** As funding permits, provide adequate number of NEEMO laptops for concurrent use in exploration and telehealth research.

**Recommendation 51:** Select crew with IT skills required to support exploration and telehealth science.

**Recommendation 52:** Select crew with basic medical skills required to support telehealth research specific to mission (vascular anastomosis on N7 and musculoskeletal ultrasonography on N9).

**Recommendation 53:** *Procedure creation and verification are time consuming, iterative and should begin as early as possible.*

**Recommendation 54:** *Developing a waterproof Actiwatch would add to the capability to perform circadian physiology experiments in extreme environments.*

**Recommendation 55:** *For all of the NSBRI Behavioral Science experiments the crew is required to provide a significant amount of information and time. It is especially important for the investigators to provide the crew with a timely post-mission report or debrief on the overall findings.*